THE

JOURNAL OF GEOLOGY

APRIL–MAY, 1899

THE VARIATION OF GLACIERS. IV[1]

THE following is a summary of the third annual report of the International Committee on Glaciers.[2]

RECORD OF GLACIERS FOR 1897

Swiss Alps.—The glaciers of this region are in general in a state of retreat. Of fifty-six glaciers observed, thirty-nine are retreating; five are stationary; twelve are advancing.

Two glaciers have been under observation during a complete period, the Zigiorenove and the Trient. The Zigiorenove had a maximum in 1852; it retreated from then until 1878 (twenty-six years); it then advanced until 1896 (eighteen years), when it had another maximum. Hence its entire period from maximum to maximum amounted to forty-four years.

The Trient had a maximum in 1845; from that time it

[1] The first three articles of this series appeared in this JOURNAL, Vol. III, pp. 278–288; Vol. V, pp. 378–383, and Vol. VI, pp. 473–476.

[2] Archives des sciences phys. et nat., Vol. VI, pp. 52–84, Geneva, 1898. At the meeting of the International Committee on Glaciers, in St. Petersburg, on September 1, 1897, Professor Ed. Richter was elected president, and Professor Finsterwalder, secretary, for the following three years. The following investigators were elected corresponding members of the committee: Professor Torquato Taramelli, Pavia; Dr. Thoroddsen, Reykiavik, Iceland; Baron Gerard de Geer, Stockholm; Constantin Rossikow, Wladikavkas; Professor Dr. Sapojnikow, Tomsk; Dr. A. Hamberg, Stockholm; M. Lipski, St. Petersburg; Professor Israel C. Russell, Ann Arbor, Mich.; M. I. Coaz, Bern; M. Chas. Rabot, Paris.

retreated until 1878 (thirty-three years); it then advanced until 1896 (eighteen years), when it had another maximum, which makes its entire period fifty-one years.

There remain still among the Swiss glaciers some marks of the increase of the last quarter of the nineteenth century, but the retreat of the glaciers is now, very generally, in full force.[1]

Eastern Alps.—The important results obtained during the current year in the eastern Alps justify the labor undertaken to obtain them. It has been shown that the partial advance observed since 1885 extends towards the east beyond the Brenner, even as far as the groups of the Venediger and the Glockner; and it is most probable that this is not the result of the great precipitation during the past two years, but is due to some more general cause; for it has been possible to predict it in the case of the Gliederferner since 1892. This same glacier has also given us some information in answer to the question—does the swelling of a glacier move down the glacier more rapidly than the rate of flow of the ice? The reply is affirmative. From 1887 to 1892 the ice had moved a distance of 110 meters, whereas the swelling had advanced 250 meters. When the swelling reached the point at which the velocity was measured, it produced a considerable increase in the velocity of the ice. Similar results are also found with the Vernagtferner.

Of these glaciers we have, definitely, twenty-six advancing, eight stationary, and twenty-six retreating. The retreat seems to be more general as we go further eastward.[2]

Italian Alps.—No results are given for these glaciers, but a careful report is made of the means taken for marking their positions, so that in the future the variations of a large number may be determined.

Scandinavian Alps.—So far as observations go, the glaciers in this region are either stationary or retreating.[3]

[1] F. A. FOREL, XVII Rapport sur les variations periodiques des glaciers des Alpes suisses. Jahrbuch des Schw. Alpenclubs, Vol. XXXIII, p. 249. Bern, 1898.

[2] Report of PROFESSOR FINSTERWALDER.

[3] Reports of DR. SVENONIUS and DR. OYEN.

Spitzbergen.—The most important work on these islands is that of Baron de Geer, who has visited them several times. He finds from the maps and photographs that the glacier of Sefström has advanced about four kilometers since 1882, but at present seems to be retreating. On the other hand, the glacier of von Post has retreated slightly since 1882 Sir Martin Conway found that the glacier, which he called the Ivory Gate, has advanced very considerably since 1870. The best accounts of the observations of Sir Martin Conway's party are found in the *Geographical Journal*, April 1897, and in the *Quarterly Journal of Geology*, 1898, Vol. LIV, pp. 197–227.

Dr. A. Hamberg has written on the parallel structure of glaciers. He thinks that this, as well as the similar structure observed in Antarctic ice, is due to stratification.[1] He thinks, also, that the movement of these glaciers is due to the slipping of successive layers over each other, and that there is practically no differential movement in the layers themselves. Dr. Hamberg thinks that in these latitudes greater pressure is necessary to convert the névé into solid ice than in warmer climates, and he thus explains the fact that many of these glaciers are not very thoroughly consolidated.

Franz Josef Land.—Dr. Nansen tells us, in the account of his celebrated polar expedition, that there are no true glaciers on these islands, but that they are covered with masses of ice sloping toward the sea. These are apparently of the same type as those described by Dr. Hamberg. Dr. Nansen also tells us that he found indications of the existence of a former glacier all along the northern coast of Siberia. He also gives us interesting descriptions of the folding and crushing of the polar ice as a result of ocean currents.[2]

Greenland.—A Danish expedition visited the island of Disco in 1897 and examined the glaciers of Blösedalen, which had been visited in 1894 by Professor Chamberlin. They found that

[1] REV. O. FISHER gave the same explanation of the horizontal markings in Antarctic ice. Phil. Mag. (5) 1879, Vol. VII, pp. 381–393.

[2] Report of PROFESSOR NATHORST.

the two southern glaciers on the western side of the valley have made a marked retreat in the interval, and they established stations for the future observations of these glaciers.[1]

Caucasus.—In this region a very large number of glaciers have been examined and photographed. They show a marked state of retreat.

Turkestan.—Twenty-six glaciers have lately been discovered and described by Dr. Ivanow in the mountain chain of Talassk-Alataou. They all have a great altitude and show indications of such a great retreat that they may perhaps disappear altogether. Many new glaciers have been examined and photographed in the mountain chain of Peter the Great. They are apparently in a marked state of retreat.

The Altaï.—Professor Sapojnikow has discovered in the last few years five glacier centers in the Altaï mountain. These contain more than thirty glaciers, some of which compare in size with the largest glaciers of the Caucasus. All of them are evidently retreating, but it is not yet possible to give even an approximation to the rate.[2]

A very interesting and full account of our present knowledge of Arctic glaciers and their variations has been published by M. Charles Rabot, under the imprint of the International Committee on Glaciers.[3] After a short account of the characteristics of Arctic glaciers he takes up in detail various glaciers, with references to original sources of information, with the following results.

The glaciers of Grinnell Land appear to have attained a maximum shortly before 1883.

The inland ice of Greenland seems at present to be at a maximum, particularly in the north. In the south a slight retreat is showing itself but too slight to arrest the general advance of the ice which has been going on during the historic period.

[1] Report of DR. STEENSTRUP. DR. STEENSTRUP went back to Greenland in May 1898 to continue the study of the glaciers there, which he discontinued in 1880.

[2] Report of PROFESSOR MOUCHKETOW.

[3] Les variations de Longueur des Glaciers dans les Regions Arctiques et Boreales, Archiv. des Sciences phys. et nat. Geneva, 1897, Vol. III.

The glaciers of Iceland began to advance at the end of the seventeenth century, at which time they were much smaller than at present. This advance continued, interrupted about the middle of the eighteenth century by a hesitating retreat in the case of certain glaciers. After this, most of the glaciers made an extraordinary advance; a veritable invasion of the ice took place, which continued during the larger part of the nineteenth century. After this advance there was a general retreat, though some glaciers are still advancing. The retreat began earlier in the north (1855 to 1860) than in the south (1880). It is less marked than the preceding advance.

There is a large volcano on Jan Mayen Land on which are nine large glaciers. A study of the records of whalers and explorers seems to show that these glaciers have advanced since the end of the seventeenth century.

REPORT ON THE GLACIERS OF THE UNITED STATES FOR 1898[1]

The end of the Eliot glacier on Mount Hood, Oregon, is supported by its lateral moraines, and is much covered with débris. On each side, one or two hundred yards from the end, the ice seems to be breaking through these moraines. This may be due to stream erosion, washing out the moraines and thus removing the support for the ice; or it may mean the beginning of an advance (*H. D. Langille*).

Professor Russell has recently published a most interesting account of the glaciers of Mount Rainier.[2] He describes the characteristics of a system of glaciers on a conical peak. Starting in general from a common névé region the glaciers separate into distinct streams lying in deep channels. The V-shaped intervals between them are occupied by smaller glaciers, which he has called inter-glaciers. He thinks the amphitheaters at the

[1] The synopsis of this report will appear in the Fourth Annual Report of the International Committee. The report on glaciers of the United States for 1897 was given in this JOURNAL, Vol. VI, pp. 475, 476.

[2] The Glaciers of Mount Rainier, Eighteenth Annual Report of the U. S. Geol. Surv., pp. 349–423. A preliminary note on PROFESSOR RUSSELL'S observations appeared in Variations of Glaciers, II.

head of some of the glaciers are the result of glacial erosion; he gives also an interesting account of dome-shaped elevations, much broken with crevasses, which seem to be a peculiarity of these glaciers; they are apparently due to elevations in the bed of the glacier. Professor Russell describes all the glaciers except those on the western side of the mountain. He finds them all very much covered with débris at their lower ends, and notes that there is a general retreat. At one point he noticed that the surface of the Cowlitz glacier, about two miles from its lower end, has recently been lowered seventy-five to a hundred feet, as indicated by fresh lateral moraines deposited on the mountain. The Carbon glacier has receded about one hundred yards between 1881 and 1896, and the Willis glacier about five hundred feet in the same interval. All the other glaciers show a marked diminution, but the amounts were not determined.

Professor Russell has kindly sent me the following account of the glaciers in the state of Washington, which he saw in 1898. It will be noticed that their number is far greater than had been supposed.

Glaciers on the Wenatchee Mountains.—In examining the records of the old glaciers of the state of Washington it was found that the Wenatchee Mountains formed an independent center of ice dispersion from which flowed several large glaciers. One is not surprised, therefore, to find small glaciers still lingering on the higher portions of this rugged and exceedingly picturesque group of granite peaks.

On the summit portion of the Wenatchee Mountains about four miles due east of the culminating pinnacle of Mt. Stuart, there is a glacier measuring by estimate one mile from north to south, including both névé and true glacial ice, and of somewhat less width. It lies on the highest portion of the western rim of a magnificent amphitheater excavated in compact granite. A view into this desolate but wonderfully attractive basin, from the narrow crest forming its eastern wall, is the finest and most instructive picture of its kind to be found in the entire Cascade region.

On the north side of Mt. Stuart, about one thousand feet below its summit, which rises 9470 feet above the sea, there are three small glaciers, situated in steep gorges or clefts in the granite, and sheltered by outstanding cliffs; combined, they would probably make an ice body less in mass than the one described above. These glaciers are narrow, and extend down the gorges where they occur for some two thousand feet. Below each there is a small and fresh-looking moraine.

The glaciers just described derive their main interest from the fact that they are isolated, being some twenty-five or thirty miles to the east of the main divide of the Cascade Mountains.

Glaciers on the Cascade Mountains.—The glaciers of the Cascade Mountains south of the United States-Canadian boundary probably number several hundred, and of these about 100 or 150 have been seen by the writer; but only a few, in the immediate vicinity of Glacier Peak, have actually been traversed. All of them are small; of those seen, probably the largest is not over two miles in length, and by far the greater number are considerably below this measure. Nearly all lie in amphitheaters or cirques. Their principal interest centers in their distribution, their relation to climatic conditions, and the fact that all of those seen are accompanied by evidences of recent recession.

There is one small glacier, however, that is worthy of special study in reference to the manner in which an ice-stream expands when not confined by walls of rock, and in expanding, forms longitudinal, or perhaps more properly, radial crevasses in its fan-shaped terminus. The glacier referred to is at the head of White Chuck Creek at the immediate south base of Glacier Peak, but on the south side of the deep canyon in which flows the branch of the creek nearest to the base of the peak. This glacier flows northward, and is in full view from Glacier Peak. The periphery of its broadly expanded extremity is not over 1000 or 1500 feet by estimate, and is broken by some four or five radial crevasses which are widest on the outer margin of the fan-shaped expansion and contract to narrow clefts which become still smaller, and disappear when traced toward the feeding névé.

This is a typical miniature example of glaciers like the Rhone glacier, Switzerland, and the Davidson glacier, Alaska.

Most of the glaciers on the Cascades have a lower limit of about six thousand feet; the majority of them are west of the Cascade divide, and are either in immediate proximity to or on Glacier Peak and the sides of lateral ridges branching from it; or else on somewhat detached peaks, some of them ten to twenty miles west of the Cascade divide. Of these outlying groups of glaciers, the most numerous are at the heads of high grade valleys in the granitic peaks about Monte Cristo, as has been observed by Bailey Willis, and on similar granitic peaks bordering the upper course of Skagit River. There is also an outlying group of glaciers on Mt. Baker and neighboring mountains.

The broadest névé fields and most numerous glaciers occur on Glacier Peak and the rugged mountains surrounding it. The snow fields in this region cover a rugged area some ten square miles in extent, and are confluent; from this gathering ground there flow several short ice streams, or rather ice tongues, as none of them have a characteristic stream-like form. The névé extends up the sides of the culminating cone of Glacier Peak and occupies the remnant of a crater still recognizable at its summit. From the top of Glacier Peak fully fifty glaciers are in view within a radius of about thirty miles. But little, if any, difference in the distribution of these glaciers can be recognized, on looking northward or southward, thus indicating that their existence depends rather on general climatic conditions, than the occurrence of previously formed cirques, or the shelter afforded by lofty peaks.

Lituya Bay, Alaska.—This bay was visited and mapped by La Pérouse, in 1786. It has the shape of the letter T. The cross arm of the bay was not surveyed but was drawn in from descriptions of the officers who visited it. La Pérouse speaks of five large glaciers coming down to the water, two at each end and one at the side of the cross arm. The maps of the Canadian Boundary Commission, made about 1894, show that the side glacier has diminished, but that the two glaciers at each end of

the bay have coalesced and advanced nearly two miles (*O. K. Klotz*).

Dr. William H. Dall, who visited the bay for the United States Coast Survey, in 1874, thinks that these glaciers were certainly a mile or more shorter then than the Canadian map shows them to be now; so that the advance seems to be still progressing.

Mexico.—The glacier on Mount Iztaccihuatl is advancing (*Ez Ordoñez*).

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March 27, 1899.

NANTUCKET, A MORAINAL ISLAND

A GEOLOGICAL MODEL OF NANTUCKET

THIS model (made at Harvard University), size 18 by 24 inches, scale 1 : 62500, or about an inch to the mile, is based on the United States Geological Survey topographic map of 1887, and on information from the latest geological surveys of the island. It was with the aim of producing an instructive relief of

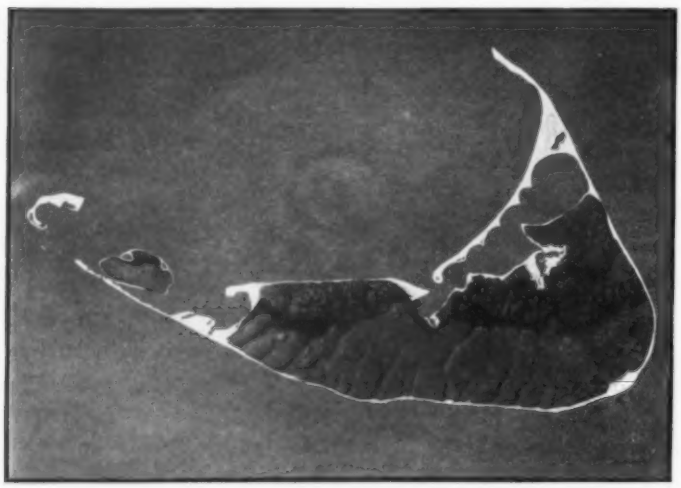
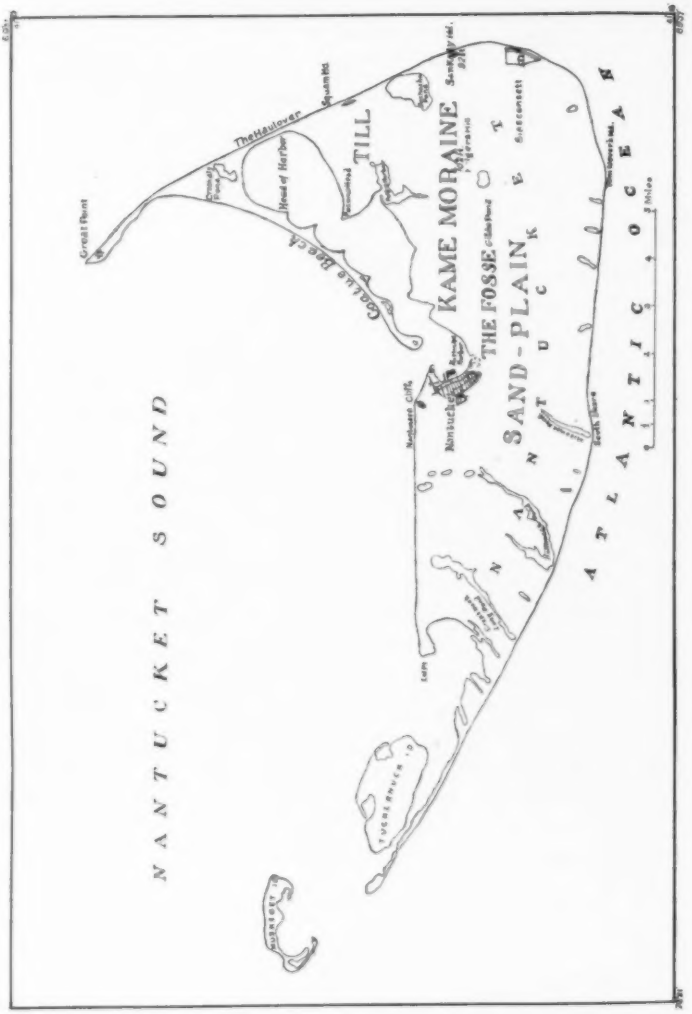


FIG. 1.—A Geological Model of Nantucket.

this portion of the deposits of the great continental ice sheet which here forms a type example of a morainal island, that this model was undertaken.

The principal topographic features,[1] shown by a profile sec-

[1] After report on "The Geology of Nantucket," by PROFESSOR SHALER, U. S. Geol. Surv., Bull. 53, 1889; surveys by J. B. WOODWORTH, U. S. Coast Survey, *et. al.*



OUTLINE MAP OF NANTUCKET.

tion across the island (Fig. 2) may be briefly described under the following divisions.

1. *The ground moraine:* an area of irregularly distributed detritus, the undifferentiated till which lies on the northeast part of the island in the vicinity of Pocomo Head. (See map, Plate I.)

2. *The kame moraine:* a belt or ridge of kame-like mounds and kettles from 20 to 100 feet in altitude, which, running through the middle of the island, seems to form its back bone. On its south side, the kame moraine, descending to the 40-foot level, grades suddenly into a smooth-bottomed trough, which reaches the breadth of over one half a mile in its widest part. The southern side of this depression ascends 40 feet by an abrupt slope into the head of the sand plain. This ditch-like conformation lying between the kame moraine on the north and the sand plain on the south, runs throughout the extent of Nantucket, and Tuckernuck, and has been termed:

3. *The fosse.*—It is supposed that this depression marks the resting place of the ice, while the steep slope rising to the head of the sand plain marks the position of the ice front during the building of the frontal plain, This escarpment at the head of the sand plain has been called *the ice-contact slope.*

4. *The glacial sand plain:* which, falling gently from the terrace at its head to the sea on the south, represents the sand and gravel deposited from the streams as they flowed from the glacier front. The plain has a relatively smooth surface, sloping in its two miles of extent, from the 60-foot level to the cliff where the sea has cut the 20-foot level. At rather regular intervals of a quarter of a mile, the plain is interrupted by shallow troughs. These grade very gently into the head of the sand plain, and continue southward until truncated in their deepest expression by the seashore. These creases are today

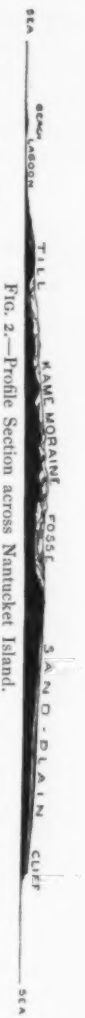


FIG. 2.—Profile Section across Nantucket Island.

practically dry, and represent the old drainage channels of glacial time. Some of them can be traced, not only toward the head of the sand plain, but extend quite through the kame moraine to the harbor on the north.

5. *Ponds or lakelets.*—There are several types of ponds on Nantucket. The most prominent lie in the lower ends of the long narrow drainage channels across which the along shore action has built barrier beaches. Hummock Pond, Long Pond, Micomet Pond, etc., are the largest of these basins. Sachacha and Gibbs Pond, by their circular forms alone would seem to be of different origin. Gibbs Pond lies in a depression of the fosse, Sachacha in a depression in the kame moraine across which a barrier beach has been thrown. Croskaty Pond is simply the unfilled enclosure between the trailing spits of Coatue Beach and Great Point. On the inner side of Coatue Beach, lagoon-like ponds have been formed behind the successive growths of sharp cusps. "Three of the cusps on the inside of the Coatue Spit, have no lagoons, but as the other two have, and since they are nearer the end of the spit and hence probably later formed, it is quite likely that the earlier formed forelands also began with lagoons."[1]

Professor Shaler has ascribed these Coatue cusps to tidal whirlpools. He says: "From a superficial inspection it appears that the tidal waters are thrown into a series of whirlpools, which excavate the shores between these salients and accumulate the sand on the spits."[2]

6. *Marshes and swamps* are plentiful and of origin similar to the ponds, the swamps as a rule being but the more advanced stage of pond-filling.

7. *Shoreline topography* is well exemplified. Nantucket's south side shows a coast well straightened by the dominating currents; the irregularities have been smoothed by beaching across the inlets and nipping the sand plain. A large part of the eroded material has gone to build up both the long spit extending toward Tuckernuck, and the rounded cusp or "apron"

[1] F. P. GULLIVER: Proc. Am. Acad. Arts and Sci., Vol. XXXIV, 1899, p. 219.

[2] Bull. U. S. Geol. Surv., No. 53, 1889, p. 13.

which lies between Tom Never's and Sankaty Heads. Greta Point is made from the waste of the cliffs on the eastern side. Coatue Beach represents the tendency of the waves to straighten the north shore.

These shore forms are changing rapidly. The spit, formerly lying in front of Tuckernuck, for example, has been driven back and the island cliffed, sending out two wing bars, the western reaching a little beyond Muskeget.[1] At "South Shore" the foreland has been aggrading, while the blunted cusp near Tom Never's Head has worn nearly away.

Ten years ago Professor Shaler wrote:[2] "About one third of the coast line of Nantucket appears now to be undergoing erosion. At the eastern extremity of the island the erosive action appears at present to be limited to the section from the southern end of the Sankaty bluffs to a point just beyond Haulover Beach at the head of Coatue Bay. In 1873 Professor Henry L. Whiting found by a resurvey of this portion of the shore that the eastern or sea side of the coast at the Haulover had receded by an average of about one hundred feet since 1846. Between Sachacha Pond and the Haulover, especially at Squam Head, the wasting is evidently at this day quite rapid, probably amounting to at least a foot a year. The southern coast westward from Tom Never's Head, especially the section west of Weedweeder Shoal, is also the seat of considerable, though apparently inconstant, wear. A remarkable but probably temporary change has recently taken place in the long spit which forms the western extremity of the island as it is delineated on the Coast Survey maps. Twenty years ago this spit at low tide constituted an almost complete bridge extending from Nantucket to Tuckernuck Island. Of recent years this point has in good part been washed away almost down to its base near Further Creek. It seems possible that the existing separation of Tuckernuck from Nantucket may have been brought about by the action of marine currents within a relatively short time."

[1] U. S. Coast and Geod. Surv. chart, No. 7, 1898.

[2] *Op. cit.*, p. 51.

The following table gives the geological horizons recognized at Nantucket and the corresponding topographic features which are represented in the legend of the model by separate colors.

POSTGLACIAL	RECENT	Swamps and Marshes Ponds — four types Shoreline; beaches, spits, bars, cusps, cliffs
PLEISTOCENE	LAST GLACIAL EPOCH	Ground Moraine Kame Moraine Fosse Frontal Sand Plain } Terminal Moraine
	OLDER PLEISTOCENE	Sankaty Beds, shell deposits
CRETACEOUS		Clays — artificially exposed (not indicated)

I am indebted to Professors Shaler and Davis, and Mr. M. S. Jefferson, for helpful criticism on this model, and especially to Mr. J. B. Woodworth, whose valuable aid has much increased its merits. G. C. CURTIS.

A SKETCH OF THE GEOLOGY[1]

The island of Nantucket, which has been made the subject of a model by Mr. Curtis, is one of the most instructive portions of the terminal moraine of the last ice epoch in North America, because it is the most distinct and isolated of these glacial accumulations. Set in the waters of the ocean far to the south of the morainal belt of Cape Cod, and distant nearly its own length from the neighboring island of Martha's Vineyard, the peculiari-

[1] Written by J. B. WOODWORTH at the request of Mr. G. C. CURTIS.

ties of its glacial form, despite the low relief of the island, are readily discerned.

This island, more than any other one of the New England islands,[1] approaches closely the purely morainic type. On Martha's Vineyard, Block Island, and Long Island, the relief is so far influenced by the topography of folded and eroded beds older than the moraine, that the true morainic expression is not fairly seen. It is in the nature of glacial drift to mask to a large extent the older rocks on which it lies. The drift of Nantucket affords no exception to this statement. Beneath this mantle of till, gravel, and sand, whose relief is shown in the model, there is a basement of pre-Pleistocene clays and older Pleistocene beds, which are exhibited in the sea cliffs on the east coast, and again on the north shore. These pre-morainal beds give rise to certain peculiarities in the topography, forms which even the morainal deposits do not entirely conceal. Remove both the moraine and the plain of gravel and sand on the south side of the island, and these older deposits would still stand above the present sea level as a number of small islands, one at Sankaty Head, one at Squam Head, and a larger islet about the size of Tuckernuck, extending westward from the site of the town of Nantucket. Other small islets might remain where the later drift now covers these older rocks.

The oldest known formation on the island is a bluish clay, probably of Cretaceous age. This clay makes up the ridge south and west of the town of Nantucket. The beds of this series are highly folded, as are also the strata of the same, and even more recent, date in the islands westward to Staten Island. Beneath these beds at an unknown but probably not great depth we should expect to find the extension of the granites and gneisses of southeastern Massachusetts.

Newer than this oldest clay formation is a series of sands and sandy clays containing a Pleistocene marine fauna, that of the well-known Sankaty Head beds. That these beds are older than

[1] A name proposed for the islands from Nantucket westward off the southern coast of New England, having a common geologic and geographic development.

the moraine is shown by the tilting and dislocation of the strata under the Sankaty Head lighthouse, their truncation by erosion and the unconformable deposition on them of the moraine, a relation first described by Upham, who showed that the beds do not belong to the so-called Champlain epoch as Dana was first led to suppose. Northward, at Squam Head, similar beds occur at high angles with folded clays, indicating that a profound disturbance of the strata over the site of the island took place sometime after the deposition of the older Pleistocene. Opinion is not unanimous concerning the cause of this and the similar dislocations which affect the islands of this group. According to one view, the dislocations originated in movements taking place in the earth's crust beneath, being simply a more pronounced phase of the disturbance which marks the "fall line" from New York southward at the inner edge of the coastal plain. Another view supposes the strata to have been disturbed by the mechanical action of an ice sheet advancing upon the soft strata of the Atlantic coastal plain. Since the action took place long before the deposition of the moraine which constitutes the chief feature of the island, the question need not be debated in a paper dealing primarily with the interpretation of a model of these more recent features.

The superficial formations of glacial origin on Nantucket appear in three very distinct belts extending east and west across the island and appearing on the dependent island of Tuckernuck. The small, wave-washed isle of Muskeget is probably a modified remnant of one of these belts. These deposits reappear on the easternmost part of Chappaquiddick. These bands may be spoken of as the kame moraine, the fosse, and the frontal plain. North of the hummocky ground, known as the kame moraine, in the eastern part of the island, is a small area of till-covered land. It seems to be the unstratified débris left upon the surface when the ice-sheet melted away, and may be dismissed with this explanation. Everywhere bordering the island is a fringe of recent marine deposits, in the making of which the original outline of the island has been much altered.

The significant features in the glacial formations are assembled in the accompanying diagrammatic cross section.

It is most convenient to consider the frontal plain first in describing the above named features of the island. This plain begins rather abruptly on the north as a terrace overlooking a more or less depressed region. The height of the plain along

Fig. 4.— Cross section (diagrammatic) of the Island of Nantucket, showing the relation of the kame moraine (*A*), the fosse (*B*), and the frontal plain (*C*). *D* is the present beach. The dotted line represents the supposed profile of the ice sheet when the frontal plain was building.

this summit line is, where greatest, about 60 feet above the sea level. The slope of the terrace to the fosse on the north is well marked, but not so steep as that of the typical moraine terrace of Gilbert,[1] or so sharply cuspate as the ice-ward edges of the sand plains described by Davis[2]. Yet this slope taken in connection with the fact that the plain inclines southward with well defined drainage creases, and that the materials are coarse at the crest line and grade into finer gravels and sands southward, affords good evidence that the plain was built against the front of the ice-sheet by excurrent streams. Viewed in this light, the terraced head of the plain indicates the east and west line along which the ice front stood in its southernmost extension.

This ice-contact slope is most distinct in the eastern part of the island, where it turns to the southeastward, as if the ice sheet extended seaward in this direction, covering at least the area now forming the Nantucket shoals. In the vicinity of the town of Nantucket, the hillock of pre-Pleistocene clays already mentioned has given rise to the type of sand plain which is dominant on Martha's Vineyard, one in which for the greater part of that island, the top of the sand plain was not built up to the base of the ice front where that rested on elevated ground. On the

[1] Lake Bonneville Monograph 1, U. S. Geol. Surv., 1890, pp. 81–83.

[2] Bull. Geol. Soc. Am. Vol. I, 1890, p. 195.

western part of the island and again on Tuckernuck, the ice-contact slope can be distinguished, affording a base line of reference from which to work out the relations of the glacial deposits to the ice sheet.

Accepting the slope at the head of the plain as denoting the position of the ice front, it follows that the fosse and the kame moraine are features originating in the area occupied by the ice. The fosse is simply the unfilled ground between the head of the plain and the belt of accumulations known as the kame moraine.

The kame moraine is supposed to be contemporaneous with the sand plain; one was building up by the action of excurrent streams outside of the ice while the other was accumulating inside the ice by the combined action of ice and water. This idea that the kame moraine is not frontal but submarginal in relation to the ice sheet by which it was built, first suggested, it is believed, by Salisbury for certain portions of the terminal moraine westward on the mainland, is consistent with the interpretation which has been placed on the origin of the kames near the heads of sand plains. Both ice-laid and water-laid drift tend to accumulate in the form of knobs and basins in this situation. At present, the explanation of the phenomenon can hardly be said to rank as an hypothesis, much less as "demonstrable theory."

One supposition is that the kame moraine marks the site of an earlier frontal deposit, *e. g.*, a sand plain, subsequently overridden by the ice sheet in its advance to the line marked by the head of the frontal plain. Stratified beds of sand and gravel seen under a coating of till in patches of kame moraine, as at Bridgewater, Mass., and the sandy clays under the till of the Nantucket kame moraine, show the possibility of the extra-glacial origin of the original deposit. But this explanation does not account for the seeming regularity in the occurrence of the belt of kame moraine at a distance of from half a mile to a mile back of the head of the outwash plain.

A second supposition makes the kame moraine built up under the lip of the ice sheet in the manner in which débris was seen

accumulating in that situation by Chamberlin in the Greenland glaciers. Applying the observations made by Chamberlin upon the shearing of the upper ice over the lower and the involution of drift which thus comes about, to the case of the Nantucket type of terminal moraine, we may fairly suppose that when the moving ice sheet became blocked against the head of its growing sand plain, the upper ice began to shear over the lower, blocked prism of ice lying behind the sand plain. This shearing movement affected the lower part of the ice sheet for a long distance back from the actual front. At a distance of from one

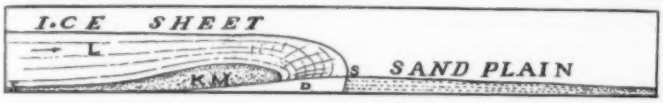


FIG. 5.—Diagram showing supposed mode of accumulation of Kame moraine. *D*, Prism of dead ice blocked by sand plain barrier. *L*, Live ice dragging up drift into K M, the position of the Kame moraine. *S S*, Principal plain of shearing.

to two miles back from the front the bottom ice began to glide over the prism of dead ice lying back of the sand plain. (See Fig. 5.) As a result of this action the subglacial till dragged along on the bottom northward of this belt was gathered in the shear zone with moving ice above and dead ice below. Most of the till accumulated within a belt about a mile wide, leaving a strip in the case of Nantucket from a mile to half a mile wide between this accumulation and the head of the sand plain in which the débris was small in amount as compared with that deposited in the sand plain on one side and in the moraine on the other. On the melting out of the ice sheet, this outer part of the stagnant prism of ice, which was relatively free from drift, would give rise to the depression which separates the sand plain from the moraine. The melting out of the inner thin portion of the wedge of dead ice with its charge of till would result in the hummocky topography which gives the moraine the striking resemblance to a belt of kames. In the case of the water-worn gravels and sands which accumulate in this belt, it is to be supposed that in the shearing movement of the upper ice over the

lower stagnant prism of ice, the subglacial drainage is interrupted and the detritus is involved in the movements of the ice as in the case of the till. It is favorable to this view that, in cases where such action may be invoked, eskers are absent, and the sand plain appears to have been fed by streams flowing off the ice sheet.

Certain ponds and furrows which lie in the kame moraine belt show that the drainage of the ice sheet, perhaps a late phase of the system, coursed through the field quite independently of the motion of the ice, which may well have been stagnant at the time. On the east, the furrow connecting Polpis harbor with the drainage crease in the sand plain has been noted by Shaler, as an indication of the movement of subglacial water as in a pipe to the front. On the other hand, creases west of the town connecting with deep, pothole-like ponds in the moraine belt suggest the holes at the bottom of falls of water off the edge of the ice sheet rather than depressions due to the melting out of blocks of ice.[1]

The question of sea level in relation to the sand plain at the time it was building is a debatable one. The absence of anything like wave action on the island above the present sea level is presumptive evidence that the sea has not stood higher than it now does upon this coast since the glacial formations were deposited. A comparison of the Nantucket plains with the deltas of glacial rivers such as those of the Malaspina district in Alaska and of Heard Island in the Indian ocean would lead us to regard the sand plain as made in the open air.

The student who is desirous of studying many interesting details concerning the geology and physical geography of this island should supplement this brief account of some of its features and the questions which they raise, by reading Professor Shaler's report on its geology.[1]

J. B. WOODWORTH.

[1] The Geology of Nantucket. Bulletin No. 53, 1889, U. S. Geol. Surv., pp. 55. 10 plates. By N. S. SHALER. This work gives references to numerous other papers concerning the paleontology and moraines of the island.

BEACH CUSPS

A FREQUENT feature of our New England beaches is a succession of stony or gravelly cusps with sharp points toward the water, situated on the upper part of the beach where the waves play only at high stages of the tide. My attention was first called to these cusps by Mr. J. B. Woodworth, of Harvard University, under whose direction the general view, Fig. 1, was taken for the U. S. Geological Survey. Subsequent study on Lynn Beach, Mass., where I obtained twenty instantaneous wave photographs, has satisfied me that on that particular shore the cusps must be ascribed to the agency of the seaweed piled up on the beach, modifying the action of the greater waves. The successive stages of construction shed so clear a light on the local

FIG. 1.—Westquage Beach, R. I.

forms, and the weed control has seemed so clear through a great variety of details observed on this beach during more than two years, that it seems time to call the attention of other observers to the point involved. Any beach photograph may have a record on it of some stage of these beach cusps.

The portion of Lynn Beach where these studies were made

is at the junction of the Nahant barrier beach with the mainland, about one hundred yards north of Hotel Nahant. It opens to the Atlantic a little south of east and is on the Boston Bay sheet of the topographic map, in latitude 42° 27′ 30″, longitude west 70° 56′ 7″. A masonry wall with a concrete walk above here caps the beach. Just below this is a mass of rounded stones from two to six inches in diameter, which have been flung up in storms. These are attached to seaweed, having been derived from the bottom off shore.[1] This belt of cobblestones passes into the sand of the beach proper by the series of cusps above mentioned. The seaward side of the heap of cobbles is, as it were, eaten out in bays, twenty to thirty feet wide with residual points of cobbles between. In the bays, the slope descends one foot in four to the almost level beach of fine sea sand. Along a line roughly tangent to the bay heads, and thus cutting across the stony promontories between, there is found an almost continuous wall of seaweed. The bays in the cobble line are floored with a gravel of texture intermediate between the stones above and the sands below. The stony points terminate in slopes much steeper than the bay floors. The gravel of the bay floors itself advances upon the beach in a series of capes, well outside the stony points and alternating with them.

The outer undulating margin of the gravel points on the sand is usually thinly strewn with cobbles from the belt above. These details may be made out more clearly with the help of the accompanying diagram, Fig. 2. The constant *recurrence* of bay and point as one walks along the beach suggests that there is a regularity in width of intervals. This is not so, however, on Lynn Beach, as appears from the diagram, measures from point to point along the beach being 21, 20, 18, 16, 22, 17, 6, 7, and 22 paces. Fainter cusps farther south toward Nahant show similar irregularity. It might be said, however, that on Lynn Beach they are commonly about twenty paces wide.

The work of the waves on the beach depends on their magnitude and direction, and on the stage of the tide. The magnitude

[1] SHALER: National Geographic Monographs, Beaches and Marshes, p. 144.

of the waves varies primarily with the wind. The great rollers that tumble up a beach some days of calm are due simply to a distant wind whose effect is transmitted faster through the water than through the air. For beach work, however, we must distinguish two orders in the magnitude of waves that follow each other even in a brief period. Anyone who visits a beach may satisfy himself that at fairly regular intervals there occurs a great wave, far overtopping the average in height and extent of

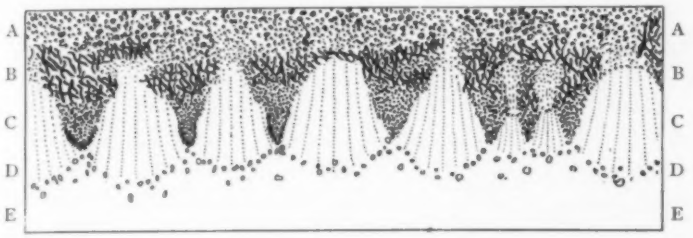


FIG. 2.—Diagram of Beach Cusps.

AA Zone of Cobbles. CC Stony Cusps.
BB Zone of Seaweed. DD Gravel Cusps.
EE Flat Beach of Sand.

advance up the beach. Now this great wave is as much more efficient than its fellows for beach work in ordinary weather, as the work of a single storm outweighs months of normal tides in building and modifying features of shore topography. As regards the stage of the tide, in a similar way, spring tides are the occasions of maximum beach work in average weather. This is especially true in all that concerns the upper beach line, where our gravel cusps are situated. All the waves, great and ordinary, have an excess of shoreward over off-shore movement during rising tide. Generally speaking it is thus during the rising of the tide that objects are driven up the beach, and during the fall that they are drawn out seaward, unless left stranded, as must happen in most cases, since both forces, though opposite in direction, have least intensity at the shoreward margin of the beach.

It results from these considerations that the greatest amount of stones and seaweed will be flung up on the upper beach on the rise of a spring tide when a strong gale is blowing from the east. The beach is not, however, a convenient place for observation at such a time, nor can it be visited save by observers resident in the neighborhood on account of floods and washouts that result and interrupt railroad and other travel. For this reason it is more practicable to study what occurs during spring tides with only moderate winds.

Such an ocasion was November 7, 1896 when I was fortunate enough to reach the beach shortly before high tide. The ordinary waves were playing up and down the bays as far as the belt of seaweed, *BB*, Fig. 2. These waves advanced with a front indented by the stony points at their maximum advance. But at intervals of about ten minutes a great wave broke evenly upon the line of seaweed, sending tons of water over the cobblestones above. The zone of seaweed in the diagram should be understood to have a depth of 12 to 18 inches. Shoreward from the crest, the weed slopes and thins. It is more or less present even on the cobble belt *AA*. But the zone represented on the diagram marks the crest. Immediately after breaking, the wave outside the zone *BB* retires, leaving considerable masses of water imprisoned behind the weed. This can only escape through occasional breaks in the wall of seaweed and at these points streams of considerable strength set outward. This moment is recorded in Fig. 3. The wave has just broken evenly along the whole line. At the instant represented by Fig. 3 the water may be seen pouring toward the opening from right and left behind the weed, streaming out through the break in the weed whence the water is distributed fan-like in every direction. A similar fan in the water to the left indicates the opening of another outlet through the weed. The quantity of water flung behind the weed barrier when such a great wave breaks is sufficient to maintain a strong current through the outlet during the rise and fall of several ordinary waves, which only play up and down the bays. As the great wave recedes we note the stony promontories,

which are completely buried in Fig. 3, and the bays between. We also note that each break in the seaweed exactly marks a bayhead. The gravel cusps below are still beneath the water. On one occasion I saw a continuous wall of seaweed flung upon the beach, saw the water ponded behind it until finally weaker points in the wall yielded to the pressure and broke, and openings were established that guided the outflow of all subsequent great waves. It seems to be clear that the bays between

FIG. 3.—Moment of wave retreat.

the stony promontories are scoured out by water escaping from behind the barrier above. That weak points should occur is inevitable. It is not conceivable that the waves could cast up a line of weed so perfectly homogeneous as to present the same resistance to outflowing water all along the line. Once a current is established across the crest, its lightness causes the weed to float away in the stream until the pebbles below are bared, and then washed down the beach in the narrow rushing stream. The weed where unbroken protects the stony ridge as the paper pattern protects glass from the sand-blast. Furthermore it concentrates the water on the unprotected spots. It may be thought

that a stony barrier might play a similar part on a beach where seaweed was absent. Great waves would surmount the crest and the water caught behind escape as best it might to the sea. Low places would doubtless occur in the crest of the line and some water flow over them. But it is to be expected that the water would filter through the mass rather than wear channels, owing to the greater specific gravity of the barrier. It is unlikely that bays could be cut out in the stones under such circumstances. It would seem to follow that such stony cusps are to be looked for only on coasts where seaweed or some similar material is abundantly thrown up.

As the tide falls, presently the waves cease to surmount the crest of the weed and each wave in receding discloses more and more of the lower beach. It now becomes evident that the scouring waters that have been rushing down the bays have spread the gravel with which they are visibly loaded in a great fan at the mouth of the bay, fairly underlying the wave-fan seen in Fig. 3, outside the seaweed. It is a true fan delta built by the stream where its waters are checked by the relatively stagnant waters outside. As these deltas are built out in front of the bays it results that in this outer line of points bays occur opposite the points of the inner stony promontories. This is at once clear on the diagram (Fig. 2). Walking along the beach at low tide the delta fans are seen nearest and are more in evidence than the stony or original cusps above. These upper cusps may well be called *residual*, as they are remnants of a continuous line in which the bays have been scoured out here and there. At Lynn the residual cusps are stony but that is not essential. In Fig. 1, the whole material is apparently fine beach sand. The seaweed that originated the form is here hardly visible but enough is on hand to show that it occurs on the beach. Attention should be called here to the fact that seaweed shrinks enormously on drying. I have made no measurements and have no data at hand, but sugar-cane, with which I am familiar, contains nearly three times as much juice as wood, and cane has certainly more woody fiber than most seaweed. For this reason

a heap of weed that may while fresh considerably modify the waves, may become quite inconspicuous when dry. Considerable quantities of weed are also carted from the beaches for manure. The only sure way to determine the presence or absence of seaweeds on a beach is to visit it immediately after on-shore storms have torn up the bottom just beyond the low tide mark. The residual cusps in Fig. 1 are rendered unusually

FIG. 4.—Residual and Delta Cusps.

visible by the wetting of a portion of their line in what seems to be an ordinary wave of a rising tide. The original photograph shows the delta cusps distinctly alternating with the residual cusps above. At Gay Head I have seen only the residual cusps, which are there constructed of pebbles an inch or two in diameter and derived from the till topping the cliff above. At that time the form was unintelligible to me, but now I am sure that at lower water the delta cusps will be seen at Gay Head too.

In Fig. 4 both series are well shown on Lynn Beach. The water stands in the hollows between the delta cusps, which show only their points on the left. The view was taken about two hours after high water. Half an hour later the waves break far

out on the beach, and only a steady trickle of water draining out of the ridge of stones and seaweed remains, in place of the violent rushing at high water. The contact of the delta cusps with the flat beach is now disclosed, and we see the cobbles already referred to strewn along the margin of the cusps (Fig. 5). The view is taken from a point on the edge of the flat beach itself and shows only the delta cusps, the residual cusps lying off farther to the left. The cobbles have probably come down the bays in the rushing streams that build the deltas. They are scattered quite at random at the foot of the delta slopes, as indicated in Fig. 2. The advancing waves of the next tide will doubtless drive some of them up the promontories on which the earlier waves are concentrated by the delta cusps.

But if the establishment of bays in the ridge of cobbles is to be ascribed to the great waves, the part of the ordinary wave is not therefore to be neglected, nor the waves of lesser tides so long as they send the water at all into the region affected. The ordinary waves intensify the form given by the gaps in the seaweed. Across the beach below all waves advance in long, even lines. As these come to the delta cusps their front is broken into tongues which are concentrated into the outer bays and made to impinge on the residual cusps in advance of the water which comes to the inner line of bays. Of all the details of the wave-work, this is one of the best established. As the wave thus concentrated on the stony promontories tries to surmount them, it is more and more deflected to right and left by the steepness of the cusps. Thus, when the wave recedes, almost all the water runs down the inner bays. This was first seen at Gay Head, where I have a record in photographs. The bays thus have a preponderance of seaward scour. On Lynn Beach this point was studied by gathering bricks along the shore and throwing them in front of the points of the stony promontories. Of twenty bricks cast into the sea where the two fans meet in Fig. 3, corresponding to the second stony point from the left in Fig. 2, one went across into the bay alongside with the next incoming wave; then a great wave brought all over the ridge of seaweed.

Some at once went on down into the bay alongside, whence they were finally removed seaward by the play of ordinary waves. Of a hundred stones flung into one of the bays, more than half were carried seaward in twenty minutes, and the others were half buried in the gravel by the scouring water digging pits in front of them. On another occasion my hat blew into the water in one of the bays, and in spite of some wind off-shore, was soon cast up on one of the promontories. There is some travel of

FIG. 5.—Delta Cusps and pebble fringe.

material shoreward up the promontories and much travel down the bays toward the sea. The great wave drives a good deal of material on shore.

The cobbles that descend over the fan deltas to the beach margin, and again ascend the promontories at the next high water, do not necessarily return to the point in the stony belt above from which they descended. It is probable that with winds setting more or less obliquely along a beach the descents will be made constantly to the right or left of the descents. I think I have seen something of the sort on Lynn Beach, but the observations were not sufficiently continuous to make this certain. In this case each cobble is liable to travel *epicycling* along

the beach, now up, now down, but always along in some lateral direction. In this form a short journey along the beach means a much longer journey along the actual path of travel, and longer opportunity for the attrition that comminutes all beach material.

On any beach where cusps occur the waves may be seen scouring out the bays and building fan cusps below. If it be asked how this begins, the answer must be that the beginning is as old as the beach. When first a ridge of cobbles was flung up by the waves and seaweed driven upon it with the rising tide, there came a moment when a great wave broke on the ridge crest to send a rush of water further shoreward. This water escaping guided the scouring of the first bays in the stony ridge. In these the waves will continue to play, deepening the scour ways, lengthening the delta cusps, and working over and modifying the mass till another spring tide or another on-shore gale builds a new barrier with stones and seaweed newly torn from the bottom. Each set of cusps may modify its successors. A new crest of seaweed flung up today is likely to have its weak points in some measure determined by the previous channels. In violent storms it is doubtful if this control is significant. Each storm probably sets the shape in which the waves must play for a long time.

As these studies have been made at a single beach, though confirmed by some observations from Gay Head and Narragansett Bay, corroboration or modification of the interpretation by others would be welcome.

MARK S. W. JEFFERSON.

A CERTAIN TYPE OF LAKE FORMATION IN THE CANADIAN ROCKY MOUNTAINS

In the Rocky Mountains of Canada there are abundant evidences of the great Pleistocene ice invasion. During considerable travel with pack horses through the valleys of the most easterly or summit range the writer had occasion to cross the continental divide by five different passes, from the Simpson Pass on the south to the Athabasca Pass on the north. This gave a familiarity with the range through a degree and one-half of latitude, or from 51° to 52° 30′ N. The evidence was everywhere so constant that a more extended region would undoubtedly reveal the same indications of a former ice sheet.

The general topography of the Rockies in this region is exceedingly rough, the mountains being disposed in long ridges, with peaks from 8000 to over 13,000 feet high, with deep, narrow valleys between.

In order to understand the special type of lake formation to be discussed, it is necessary first to review briefly the general results of former glacial action in the region. These results are evident in the drift, striations and grooves, the transportation of erratics, and in glacial contours.

Drift, consisting of unstratified clay deposits containing angular and glacially striated stones, covers the valleys and passes throughout the region examined. It varies in thickness from a thin layer up to observed sections of more than 300 feet. It is generally thickest in the valley bottoms and on the lower slopes of the mountains up to an altitude of about 500 feet above the stream beds. Above this level it gradually thins out, leaving the mountains bare at from 1000 to 2500 feet above the valleys.

Drumlins occur in many valleys, especially in those now occupied by large streams, and in some regions are so abundant as to become the most prominent feature of the landscape.

The phenomena of crag and tail, like the drumlins, are very constant and no less important in determining the direction of the ice movement. Crag and tail assumes all gradations between ridges several miles in length to those that are merely shallow accumulations of drift in the lee of slight elevations of the rock surface.

FIG. 1.—Section near Banff showing two tills.

Terminal moraines, except near existing glaciers, are far less frequent than the subglacial drift formations. Modified drift and river terraces are well marked on all the rivers as soon as they reach the plains; also in the mountain valleys of the Athabasca, Saskatchewan, and Columbia; but the smaller rivers and streams rarely show well defined terraces in the mountains themselves.

Several exposures of the drift showed evidence of two ice invasions. One of the clearest of these was discovered on the banks of the Bow River, two and one half miles east of Banff Station, on the Canadian Pacific road. Here the river sweeps against its north bank, and has laid open a section of drift more than 300 feet thick. About half way up the bluff the line between two different kinds of till is clearly marked.

The lower till is of unstratified drift, consisting almost wholly of pebbles and gravel, with but very little clay and rock dust. Quartzite, limestone, and argillite pebbles, many of which are markedly striated, make up the principal mass.

The overlying till consists almost wholly of clay, so hard as to resemble sun-dried brick, which, when struck by a stone resounds like solid rock. Interspersed at considerable intervals are pebbles not differing much from those of the lower till. Like them they are angular and striated. The bottom of these formations is not exposed, as the river rests on drift. However, two formations were later observed on the Cascade River two miles distant, which were identified as the same, and these rested directly on the Cretaceous sandstones of the vicinity. Thus only two tills are represented in this region.

The sides and summits of mountains must be examined for evidence of greater depth in the ice currents than those given by the drift formations. Near the station of Banff, which is in the Bow or South Saskatchewan Valley, about twenty-five miles from the point where the river leaves the mountains, there is a low mountain whose summit is exactly one thousand feet above the river. This mountain is of Devonian limestone throughout, and in form is a blunt ridge running transversely across the valley and partially blocking it. On the top of this mountain there are many Cambrian quartzite bowlders and other erratics which have been transported thither. The nearest point at which these quartzite bowlders are found in place is at Castle Mountain, seventeen miles up the Bow Valley. The limestone ledges are channeled, grooved and striated, in a direction exactly across this mountain, but parallel with the valley.

This mountain, therefore, must have been so deeply covered by a glacial stream that a barrier one thousand feet high caused no deflection of the current.

Proof of higher points being overrun by the ice was observed on Stony Squaw Mountain, which rises to a height of 6130 feet, or 1620 feet above the Bow Valley, and is a little to the northwest of the point just referred to. The mountain has contours rounded by ice action and the higher parts are free from débris or soil except for a few quartzite erratics, of which one, more than two feet in diameter, was found on the very summit. This mountain also is of Devonian limestone formation and consequently the bowlders have been transported hither by glacial action.

The mountains in the neighborhood of Banff show glacially rounded contours much higher than the summits of the lesser points just referred to. Grooves running parallel to the valley direction may be observed on the limestone cliffs of the mountains, from the valley bottom itself, especially in certain conditions of the light. Some of them are between 7000 and 7500 feet above sea level, and indicate that the ice was between 2500 and 3000 feet thick in this region. Up to 7500 feet above the Bow Valley at Banff, the evidence of general ice action is quite certain, but higher than this all is more or less obscure. A distinction must be made between the work done by local glaciers of the mountains and the general currents filling the valleys, but this is not usually difficult as local glaciers, unlike the general currents, were affected directly by the mountain slopes.

Evidence from other parts of the mountains is in accordance with these conclusions. Thus near Lake Louise, forty miles northwest of Banff, in the Bow Valley, striations of a general ice current were found on the summit of a mountain 7350 feet above sea level. Glacial contours are evident about 350 feet higher, or 7700 feet above sea level.

Continuing up the Bow Valley about ten miles, glaciated contours reach an altitude of about 8000 feet. Fifteen miles further up, where the river takes its source, near the Little Fork

Pass, the altitude is still higher, and reaches 8500 feet above sea level. On the other side of the pass in the valley of the Little Fork of the North Saskatchewan, the evidence is almost identical, but with a downward slope of the ice line as the valley descends to the northwest.

The highest erratic was found on a point near Mt. Assiniboine, about twenty-five miles south of Banff, on the summit of a mountain of limestone formation 8650 feet above sea level. In the course of very many mountain ascents no transported bowlders were ever observed at a greater height than this, nor on isolated summits over 9000 feet above sea level were there any evidences of general glacial action.

The indications of former large ice streams which occupied all these mountain valleys are found not only in the Bow Valley but in the tributary valleys of the Saskatchewan and Athabasca on the eastern side of the summit range, and of the Columbia on the western side. In fact no mountain valley was observed in which the same evidence was not more or less apparent, and the line between glaciated and unglaciated surfaces rarely or never appeared at an altitude lower than 7000 feet nor higher than 9000 feet. This ice line is invariably higher in regions of great elevation, near high mountain masses, in elevated valleys and on mountain passes. It is evident then, from the arrangement of drumlins, crag and tail formations, glacial grooves and striations, and the transportation of erratics, that the present drainage system was that of the ice currents, even at the time of their maximum development.

To this there are some interesting exceptions, as for instance, in the Columbia Valley, where it appears that the ice formerly moved southwards and the river now flows northwards. To find a satisfactory explanation is not difficult. This valley is exceptional among the mountain rivers in having very little gradient so that the river is sluggish and the valley is more or less swampy. In other words, it would require only a slight elevation of the region to the north or a depression to the south to reverse the direction of this stream. It is not necessary, how-

ever, to assume such a change in elevation, as a slightly greater precipitation in the north would have made this valley discharge its glacier to the south.

We have then, the following, as a summary of the indications of the nature of former glacial activity in this part of the Canadian Rockies:

1. Evidence in the drift formations that glaciers formerly occupied all the mountain valleys.

2. Evidence in certain till exposures that there were at least two distinct ice invasions.

3. Evidence from glacial contours, striations, grooves, and erratics no less than from the absence of them on isolated peaks over 9000 feet high that the former glaciers were between 1500 and 3000 feet in thickness, that their maximum height in the valleys was between 7000 and 9000 feet above sea level, and that the maximum glaciation of this region was always confined to the valleys, above which the very elevated regions and mountains, which were centers of dispersion, rose like islands.

4. Evidence, from the above, that the present drainage system represents approximately the direction of the former ice currents.

Having thus very briefly reviewed the extent of the ice invasion in the Canadian Rockies within the latitude specified, it is now possible to get a clearer idea of the special type of lake basin which is the subject of this article.

Lakes, though very numerous, are limited in size as would naturally be expected in a region of narrow valleys and steep gradients. The two Bow lakes at the sources of the river of that name, are each about four miles long by one mile wide. Outside of these lakes the great majority are smaller and are of all dimensions down to mere pools two or three hundred yards across. About one hundred of these lakes were more or less thoroughly examined and, in regard to their formation, may be divided into four classes.

1. Lakes formed in kettle holes of the valley drift, often in chains of three or four together. In this class should be included

all lakes where water has collected in irregularities of the drift. These are especially numerous near the summits of passes where the nearly level surface has not permitted the streams to cut down and drain the basins. This class of lakes shows no

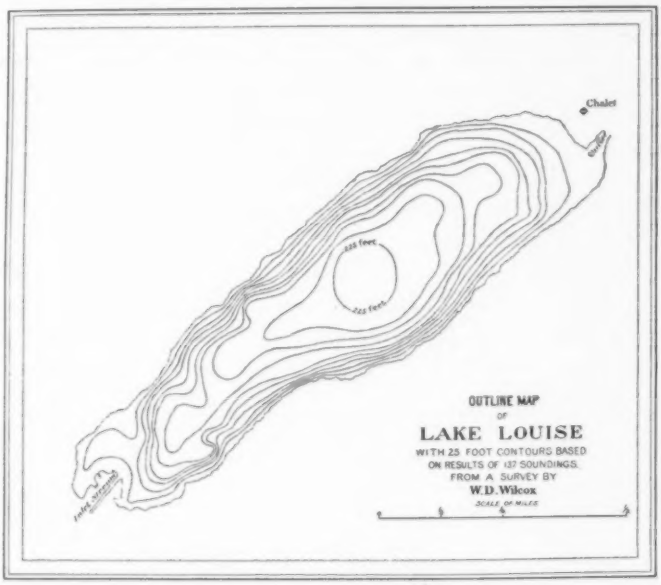


FIG. 2.

regularity of form or location. Their basins are usually shallow, and they frequently have neither inlet nor outlet.

2. Lakes dammed by terminal moraines. Only two of these were found distant from existing glaciers. Each was about a mile long and the dam of one was two miles from the end of a large glacier and that of the other about four miles.

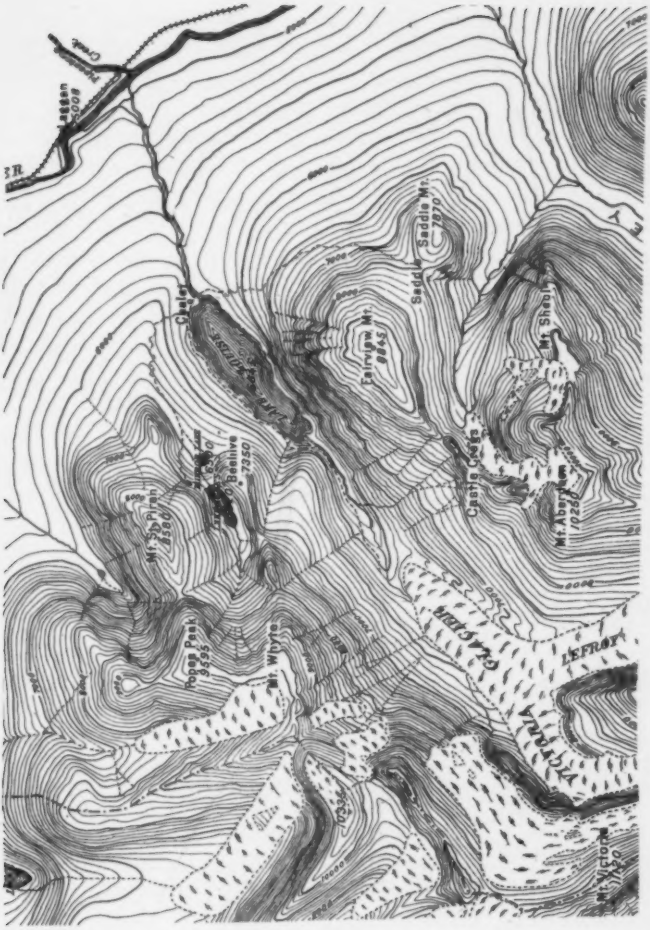
3. Rock basin lakes. Only two of these were observed, one of which was a typical cirque lake. Many rock basin lakes, however, in this region are partially dammed by drift desposits, or are otherwise of complex origin.

4. Lakes found just within the mouths of tributary valleys. These lakes are the most constant of all in their outline and position. They are invariably found where a lesser valley joins a larger one and occupy the mouth of the lesser valley. They are usually leaf-shaped and from three to ten times longer than wide.

Of this type Lake Louise is a good example and was made the subject of special study. Lake Louise is in one of the tributary valleys of the Bow River about twenty-five miles below its source, in latitude 51° 30′ N. and longitude 116° 15′ W. The shore line was carefully surveyed and mapped, after which the basin was studied by means of soundings. The accompanying map of this lake on which the contours represent the depression of the bottom below the surface, shows that the basin is very deep in proportion to its size. The basin is U-shaped with a nearly flat bottom, and with exceedingly steep sides approaching in many places a slope of forty-five degrees.

The lake occupies the end of a valley just above its junction with the much wider valley of the Bow. The catchment basin draining into this lake is an exceedingly rough part of the Rockies, with peaks over 11,000 feet high, forming part of the continental water-shed, at the valley end. The surrounding mountains are covered with considerable fields of ice, which unite to form a glacier about three miles long, measured up either one of its two branches.

A stream from the glacier has carried in clay and gravel so that a delta has formed, and filled in the upper part of the lake basin to the extent of one third of a mile or more. The fine mud carried by the glacial stream which is not heavy enough to sink at once upon reaching the quiet waters of the lake, remains suspended in the lake throughout the summer, and turns its blue-green water to a milky color by the end of August. In November the lake freezes, the inlet stream is much reduced in volume, and becomes clear, and the exceedingly fine mud settles to the bottom. This settling process continues under a thick protection of ice and snow for six months, and with few or no


Saddle Mt.
Saddle Mt.
Mt. Shasta
Fairview Mt.
Casaing Castle
Mt. Abundance
Mt. Whyte
Hoppe Peak
Mt. Hoppe
Beeline
LEFROY
CLAUDIA
VICTORIA
Victoria

convection currents to disturb the quiet of the waters, the lake becomes perfectly clear by spring.

An attempt was made to get a section of these clay deposits at the lake bottom and so determine the age of the lake. It seemed probable that by knowing the thickness of the annual deposit, and by getting an entire section, the number of years since the formation of the lake could be estimated. For this purpose a piece of iron pipe about one inch inside diameter was heavily weighted and fastened to a stout rope. This was lowered in about two hundred feet of water and allowed to fall the last fifty feet so as to carry the pipe far into the bottom. Upon lifting the pipe out, and this was accomplished with great difficulty, a core ten inches long was removed from the pipe by drying. Unfortunately this core did not represent the entire section of the lacustrine deposits so that it would have been useless to make estimates on this basis. As had been hoped, however, there were clear evidences of lamination in the slightly different colored bands of clay, though the structure was distorted by being forced into the iron pipe. As nearly as could be counted there were about one hundred bands to an inch, and on the basis of 10,000 years since the last retreat of the ice, these clay deposits would have to be between eight and nine feet thick. With a more perfect apparatus and an entire section, the age of this lake, and consequently the time since the glacial period, might be quite accurately estimated.

The Lake Louise Valley has a trend to the east as it enters the Bow Valley, as though the former ice streams had turned down stream and swept over the flanks of the mountain on the east side of the valley, while the other side shows a sharp ridge of drift descending from the base of a rock buttress 800 feet above the lake. This ridge carries a dam across the valley mouth and slightly deflects the outlet stream to the right. The outlet stream has cut down through this dam and exposed a section of drift from 75 to 100 feet deep. It is typical till of hard, blue clay, with angular or striated limestones, shales and quartzites, distributed through it.

The two valleys to the east which are similar to the Lake Louise Valley in size, direction and general features, have no lakes similarly located, but there is a more or less pronounced drift ridge on the upstream side of each. A swampy meadow in each valley corresponds in position to Lake Louise, and these meadows may represent filled-in lake basins.

Of the very many lakes of the Lake Louise type to be found in these mountains we shall only discuss one that was seen near

FIG. 4.—Lake near Mt. Assiniboine showing the dam.

the continental watershed in about latitude 51° N. at the base of Mt. Assiniboine, a mountain about 12,000 feet in altitude. The lake was small (Fig. 4), probably one third of a mile long, and occupied the opening of a tributary valley to a stream of moderate size. Owing to distance from the base of supplies in this wild region, there was no time to make an examination of the ridge damming this lake, but it was undoubtedly of drift as was indicated by an abundant forest growth upon it. The shape of this lake, the position of the outlet, and the course of the stream deflected by the drift ridge, are clearly shown in the photograph. This lake is typical of this mode of formation.

A study of many cases showed that a certain ratio between the confluent valleys is necessary to the existence of this kind of lake basin. If the confluent valleys are nearly equal in size, thus showing that the glaciers formerly occupying them were probably of the same dimensions, the drift ridge projects as a long tongue between the two valleys and no basin is formed. If the ratio between the confluent valleys is about three to one or more, the drift ridge is thrown across the mouth of the lesser

FIG. 5.—Lake Louise from the upper end showing the dam.

valley and a lake basin is formed. If, however, the ratio is exceedingly great, the lake basin will either be small, or totally lacking, and will be farther within the lesser valley, as though the lesser glacier had been set back by the great volume of the main ice current.

Many lake basins of this type have been entirely filled in by deposits of glacial streams and the growth of sphagnum mosses or forests which have made peat swamps or flat meadows where a lake basin formerly was.

So constant is this type of formation, that, upon seeing the ratio between certain mountain valleys, the existence and location of such lakes may be predicted with almost invariable success before the lake has been actually seen. The valley of the Little Fork of the Saskatchewan, which is about thirty miles long, has five streams from the west tributary to the main stream, and every valley has a long drift ridge on the upstream side thrown across the openings of the lesser valleys, resulting in the formation of three lakes and two swamps.

The outline of these drift ridges when looked at from a distance and at right angles to them is quite constant in character. Starting with the rock buttress where the formation commences, the drift is at first very steep and clings to the slopes of the rock. As it continues downward, the slope rapidly decreases in a graceful curve till it approaches an angle of about ten degrees. This slope continues through a great part of its length, only to increase again just before the ridge vanishes as a topographic feature. This curve is represented in almost every one of the many examples observed, and, like the outline of drumlins, may be a mathematical curve depending on the physical nature of ice. In general the outlines of these ridges are smooth like a drumlin or tail formation, and not like a terminal or lateral moraine.

A number of sections were found where streams have cut down through the drift and exposed sections from a few feet up to two or even three hundred feet. In all such cases the formation of the ridges was found to be a regular till without internal arrangement.

The horizontal projection of these ridges is slightly curved, and remarkably similar to what would be the lines of medial moraines on confluent glaciers from such valleys. Moreover these curves are assumed regardless of the lesser topographic forms and thus give another proof that they are not moraines.

To summarize the characteristics of these drift ridges, we have the following:

1. Throughout the valleys of the region under discussion,

and by implication a much more extended area, a certain kind of drift ridge is more or less evident wherever a small valley joins a larger one.

2. These ridges are always found between the confluent streams, are crossed by the lesser stream, and are nearly parallel to the larger valley.

3. They sweep out into the main valley or across the mouth

FIG. 6.—Drawing to show probable flow of ice currents from Lake Louise valley.

of the lesser one somewhat proportionally to the probable former dimensions of the glaciers occupying them.

4. They are of unstratified drift, whose upper ends rest against a rock buttress between the confluent valleys.

5. They have a constant characteristic curve of outline, and of horizontal projection, the latter corresponding to what would be the lines of medial moraines on uniting glaciers from such confluent valleys.

6. They are not sharp crested, but are evidently a subglacial

formation and their direction is not, like terminal or lateral moraines, influenced by minor topographic features.

From the foregoing it seems evident that these drift ridges are a subglacial formation disposed under the ice along the same lines as medial moraines would have had on the glacier surface, and that they are a kind of crag and tail formation resulting from the union of two glaciers. The fact that a rock buttress is the initial point of these drift ridges, shows that they were not the result of a short action at the close of the ice invasion. The change of all the preglacial V-shaped valleys to the present U-shaped form was accomplished by a great amount of erosion and transportation of débris. The rock ridges which commence and probably underlie the drift ridges are portions of the old V-shaped valleys which by their position have been preserved. They represent lines of protection from severe erosive action, and it is therefore necessary that the rock should be preserved along the same line in which the drift has been deposited. These lake basins are therefore possibly in many cases rock basins, but made much deeper by an overlying drift formation.

It remains to inquire why the glaciers from the tributary valleys did not cut out channels of even gradient, instead of leaving these basins. Thus the bottom of Lake Louise is 230 feet below the very lowest part of its dam, and the lower surface of its glacier must have ascended this slope upon entering the Bow Valley. A study of existing glaciers shows that a tributary is always narrower after confluence with a larger glacier as a result of the more rapid movement of the ice current. It is probable that this contraction takes place in the vertical dimensions as well as the horizontal, and thus causes the under surface to ascend, while of course the upper maintains its level.

WALTER D. WILCOX.

THE PIRACY OF THE YELLOWSTONE

EVER since the Grand Canyon of the Yellowstone was introduced to the general public, it has enjoyed a well-deserved fame for its grandeur and for the unrivaled beauty of its coloring. To the physiographer it has stood as a type preëminent of a very young river valley in the trench stage of development. All who have seen it have been profoundly impressed by it, and by many it is considered the most satisfying object of beauty in the region. It is now possible to introduce this already famous canyon in a new light, as the scene of one of the greatest acts of piracy on record.

The Yellowstone Lake, with an altitude of 7741 feet A. T., lies in a depression in the southeastern part of the great rhyolite plateau of the Yellowstone National Park. On the east of the lake the land rises rapidly to the high crests of the Absaroka range. On the north and west, and for the most part on the south, the land rises to the general level of the plateau, eight hundred to a thousand feet above the lake. North and south of the lake, and fringing the west shore, are considerable areas of flat land, not far above the present lake level and plainly lacustrine in origin.

The long southeast arm of the lake is seen to be the lower end of a magnificent mountain valley, here submerged. Beyond the lake the valley extends over thirty miles to the southeast, past the limits of the Park, up into the heart of the Absarokas. The upper Yellowstone River occupies this broad vale, at present wandering on a gradient which compels it to constant deposition, the flat bottom of aggraded material averaging over a mile in width for twenty miles southeast of the lake. This valley is manifestly very old, and it has its counterpart in the Lamar Valley in the northeastern part of the Park. It has been shown[1]

[1] ARNOLD HAGUE: The Age of the Igneous Rocks of the Yellowstone National Park, Am. Jour. Sci., 1896, I, p. 454.

that both these valleys were old and well developed before the rhyolites were poured out to form the Park plateau in Pliocene time. The lower courses of both these valleys are masked by the rhyolite flows, and the lake depression itself may be suspected to be a great mountain valley obstructed by lava flows.

The divide west of the lake lies on the flat-topped rhyolite plateau, and at various places there are cols of significant shape and altitude. Plainly some of them have been lines of drainage, showing that at some time water has flowed across the divide, making well-defined valleys. The stage road from the Upper Geyser Basin to the "Thumb," as the west arm of the lake is locally called, passes through one of these notches at the continental divide east of de Lacy Creek. It is rather a narrow valley, with walls perhaps a hundred feet high, cut right across the crest of the divide, yet flat-bottomed and at present marshy and undrained.

It is believed that this whole region has been covered with ice moving west from the Absarokas and north from the Tetons, and it may easily be supposed that in the unequal recession of the ice margin, obstructed drainage would give rise to overflow to the west, establishing channels that would be abandoned on a further recession of the ice. But there is one such channel which gives evidence of very long use even after the ice had left the plateau. This is a "windgap" between Overlook and Channel mountains at *D* in the map, page 263. Here a canyon with walls several hundred feet high cuts across the present divide, down almost to the contour of 7900 feet. Yet this surprising notch is poorly drained, puny streams starting from the marshy col and flowing to opposite oceans. The eastern one is an unnamed branch of Grouse Creek, the one to the west, called Outlet Creek, leads into the Heart Lake basin and so south to the Snake River. This notch has been recognized as a former outlet of the lake, and the fact is well known that the lake was once at this altitude, about one hundred and sixty feet above its present level. Lacustrine deposits are recorded on the United

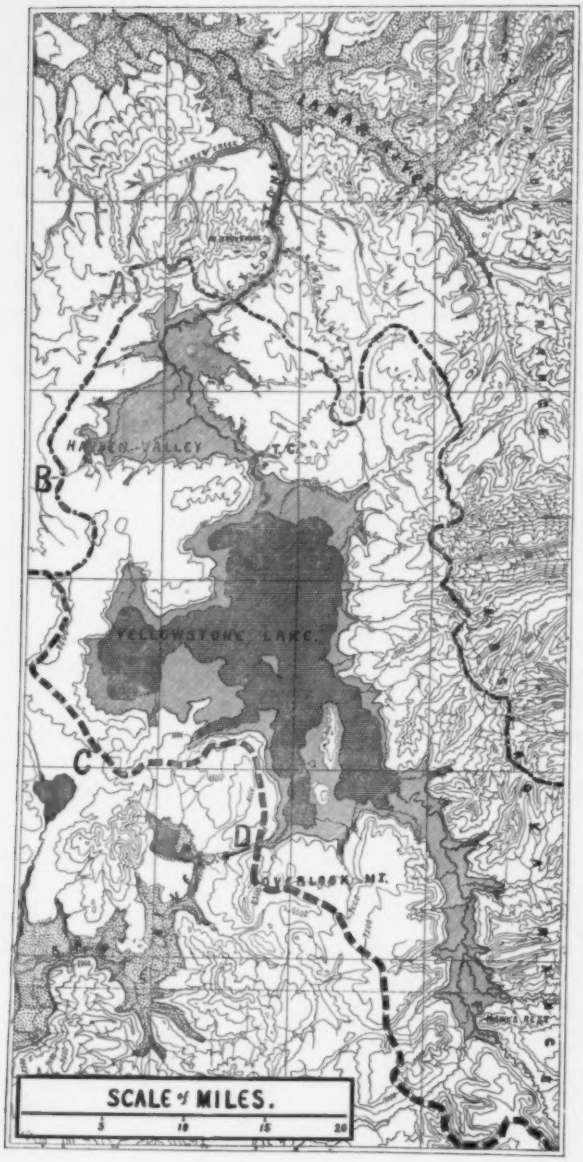


FIG. 1. Map of the eastern part of the Yellowstone National Park. The heavy dotted line *C D* is the present continental divide, the lighter line *B A* the ancient divide. The heavy hachured areas are present lakes, light hachured area is the ancient lake.

States Geological Survey maps,[1] practically up to the 7900-foot contour, all round the lake, and at its foot, to a point four miles below the present lake outlet, at Thistle Creek Canyon, marked *T. C.* on the map, p. 263. At this level also are found terraces, old sea cliffs and beaches, and while other shore phenomena are found at lower levels, as, for example, at the sixty-foot level, yet in some respects the most strongly marked records are at the higher level.

Through the Thistle Creek narrows to the north, the country flattens down into the Hayden Valley—a triangular depression in the plateau, ten miles east and west by seven or eight miles north and south. The surface of this depression is covered largely with moraine deposits of glacial drift, and all round this valley, particularly in the drift, the hills show a significant profile, which, immediately below the Thistle Creek Canyon, is undoubtedly terrace and sea cliff. On the upper courses of Trout Creek, and across the river, east of Crater Hills, similar profiles are seen. The central portion of Hayden Valley is a very flat plain, extending along the two streams, Alum and Trout Creeks. These two streams are wandering on a very low gradient, Trout Creek showing as beautiful an example of oxbows on a small scale as may be found anywhere, and in its wandering, its valley walls show stratified clays, the fresh-cut bank in one place near the roadway standing at a height of over thirty feet against the stream (Fig. 2, *A*, *B*).

FIG. 2.

At the Grand Canyon the strongest impression one gets is that the canyon is extremely young, that the river is still actively corrading at bottom, and the walls all along are actively sloughing, by every process of degradation. Yet this impression of youth has its greatest emphasis, only when seen from the east flank of Mt. Washburne. Here, at an elevation of about two thousand feet above the plateau, the whole eighteen miles of canyon is in view, from the Falls to Junction Butte, dwarfed now

[1] Yellowstone National Park Folio, U. S. Geol. Surv., Washington, 1896.

by distance into a simple roadside ditch. With this view, it is easy to see that the canyon is not all the same age. The north half of it is distinctly older than the south or upper half. In the north half the shoulders are markedly rounded, the walls less steep, the stream at bottom has long ago found an axial equilibrium with the material it has to handle, and is not deepening or widening its bed in any striking way. It is a surprise to notice, too, that Broad Creek, which empties into the Yellowstone River just at the east foot of Mt. Washburne, has a canyon every whit as wide, as deep, and with shoulders as rounded as has the main canyon at this point.

One cannot help wondering why the Yellowstone Canyon is so young only above this point; why the deep stratified clays in Hayden Valley; why the terrace and cliffs at the high level in Hayden Valley. Why did the Yellowstone Lake abandon a good outlet at Overlook Mountain, and flow off to the north? The explanation may be read from the correlation of the available data as follows.

The Yellowstone Canyon for five miles or so below the falls is extremely young, the occupation by the river representing only a fraction of postglacial time. On the recession of the ice from the region, the plateau of rhyolite stretched untouched by the river action, from the south base of Mt. Washburne southeast across the site of the present canyon, at the general plateau level of about eight thousand feet. There was no canyon, and no Yellowstone River there. The two depressions in the plateau, Hayden Valley, and the present lake basin, if they existed in preglacial time, outflowed by some other route, at present unknown. On the recession of the ice from the region, these basins overflowed to the west, over available cols. Possibilities of such drainage lines, besides the one mentioned on the road to the "Thumb," may be suspected at *A*, *B*, *C*, and *D*, on the map, Fig. 1. But the one which established itself for greatest permanence was the one described at Overlook Mountain.

Now taking the topographic map and supplying a shore line for a lake outflowing at this channel, the surprising fact is shown

that such a lake not only pushes itself into the great valley over sixteen miles to the southeast, but it goes on thru the narrows at Thistle Creek, on the very level of the terrace and sea cliff noted. It covers all the Hayden Valley, with the exception of the very peaks of Crater Hills, and extends on past the falls and the Canyon Hotel to Inspiration Point, thus making a great twin lake extending over fifty-one miles from Inspiration Point on the north to Hawk's Rest far down into the Absarokas on the southeast. This greater lake is shown in the map by the lighter shaded area. The darker shading showing the area of the present lake.

The only assumption necessary in this reconstruction, is the absence of any considerable crustal deformation in postglacial time, and so far as known there is no evidence of any appreciable change of this kind in the area during this time.

Let us look now at the character of the Grand Canyon as it appears among its neighbors. The dominant topographic feature of the northeast part of the park is the great Lamar Valley. It is over two thousand feet deep, and its walls have receded under the tooth of time until a broad and generous vale a mile and more in width at bottom extends for twenty-five miles above the point of its confluence with the Yellowstone River. This vale was old in the Pliocene. It was deep and of generous size before the rhyolites and basalts were poured out to mask the old drainage and make the plateau in which the Yellowstone Lake and Canyon now lie. Once see this great valley and the impression is inevitable that the Yellowstone Canyon is a very late comer. Moreover, as a canyon it is not of much more importance than its neighbor of Tower Creek on the west. In short, the Yellowstone Canyon, from Junction Butte back to the east flank of Mt. Washburne, is not the work of the Yellowstone River at all, but was made by Broad Creek, then a small tributary of the Lamar, of no more consequence than Tower Creek, which joined it from the west. Its canyon may have been begun in preglacial time, but long after the general ice-sheet had left the region it remained an obscure stream, slowly

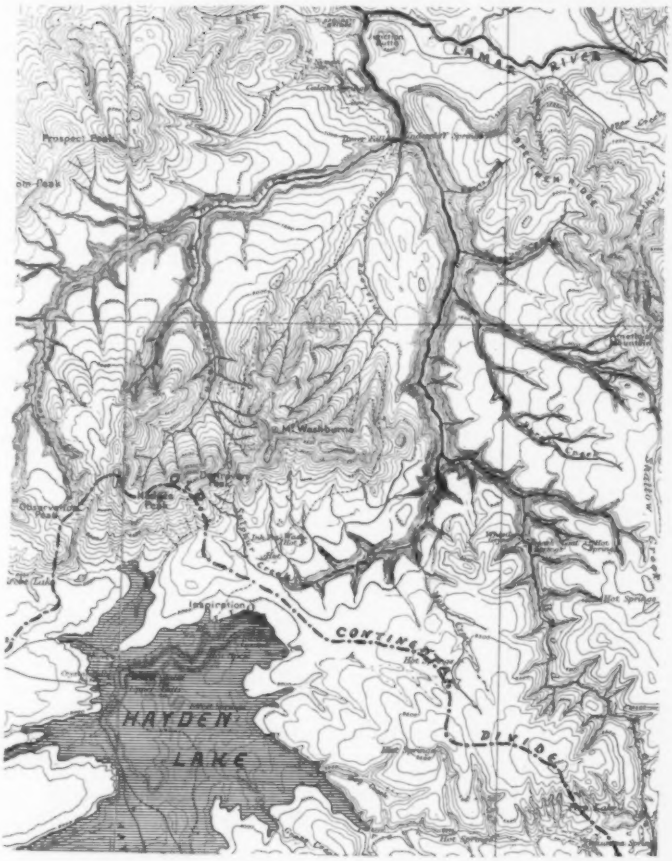


FIG. 3. Map of the scene of the piracy, showing relative size of the canyons of Tower Creek and Broad Creek. The contours of Broad Creek Canyon are supplied in place of the upper half of the present Yellowstone Canyon.

pushing its growing gorge back into the rhyolite of the plateau.

In Fig. 3 the site of the future Grand Canyon is represented, the contours being copied from the U. S. Geological Survey topographic map, with the exception that south from the mouth of the present Broad Creek the contours of Broad Creek itself are supplied, in the line of drainage of Sulfur Creek. The col between the Sulfur Creek gorge and the greater lake lay about two miles north of Inspiration Point in the old Continental divide. Yet the Sulfur Creek pirate was a long time eating thru this two miles or so of barrier. And all this while—a good fraction of postglacial time—the great lake was giving its water thru the Overlook Mountain channel to the Snake River, and the beaches, terraces, and sea cliffs were building at the contour of 7900 feet—about 160 feet above the present lake level. In the Hayden Valley part of the lake, similar beach records were making, and the stratified clays were being deposited off-shore.

The rate of advance thru the col by the Sulfur Creek pirate would depend upon three factors, the volume and gradient of the stream, and the nature of the rhyolite. The volume of water was not large, being only the drainage from the south flank of Mt. Washburne and the east flank of Dunraven Peak. The gradient was high, about 1500 feet, in the Sulfur Creek branch alone, while the rhyolite in the path of the canyon was in admirable condition for easy working.

The rhyolite, on first cooling from its flow, was hard and firm of texture, the obsidian or volcanic glass being one phase of it, usually found at the surface. In deeper levels it may have been as hard and crystalline as basalt; but the hot vapors from below have attacked the firm rock and in many places totally changed its character, making the felspars over into kaolin and leaving the once firm lava a crumbling mass, almost like slaked lime. Yet this solfataric action has not been universal. It has worked very effectively in certain areas, while in other places the solid rhyolite has wholly escaped the decomposing action. Were this not so, the canyon would long ago have advanced clear to the present lake.

The trend of physiographic history in the region was suddenly changed when the col was cut thru by the advancing canyon. The water of the lake began to flow out to the north, the increased volume very greatly hastening the deepening and widening of the trench. The lake level was rapidly lowered, the Overlook Mountain outlet was suddenly abandoned, and with this change the continental divide was transferred to its present position south of the lake. The lowering of the lake level was extremely rapid for a hundred feet, while the outlet was cutting in the decomposed rhyolite merely. In the hundred feet of rapid lowering but slight traces of shore action on the lake could be expected. But this rapid lowering was checked when the river reached the 7800-foot contour, for it came upon a wall of firm, undecomposed rhyolite standing squarely across its path — the site of the present Great Falls — and the river settled down to the task of sawing this barrier in two. It is still at the task, with nearly a quarter of its work yet to do. This barrier is only about a hundred feet thick, and is very plainly marked in the brow of the canyon wall, forming a narrow gateway thru which the water rushes. The inner walls of this gateway are very precipitous, as may be seen in the familiar view of the Great Falls. Immediately above and below this gateway the canyon walls fall away to a wide V-shape in section. The plan, Fig. 4, shows the relation of the barrier to this fall, and how the canyon is narrowed to the precipitous gateway in the barrier. As seen from the down-stream side, this barrier is evidently cut down a little over half its height, and one may easily conjecture that this fall, which is now 312 feet high, must have earlier been much higher, perhaps even 700 feet. The present brow of the fall is near the up-stream face of the barrier, and standing at the brow one may see that the firm rock of the barrier projects at the bottom on the east side of the stream, as a

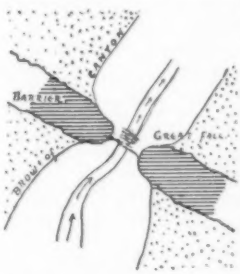


FIG. 4.—Diagram of the barrier at the great fall.

shelving ledge upon which the water is ceaselessly pounding, as shown in longitudinal section in Fig. 5. So this fall may be said to be showing signs of old age—that is, the rapids phase of development has already begun.

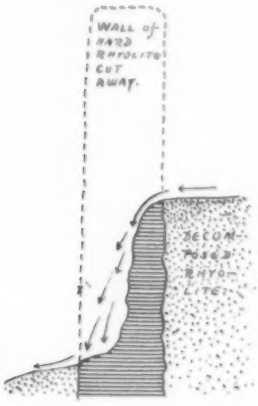


FIG. 5.—Longitudinal diagrammatic section of the great fall.

With the lake outlet approaching this barrier at the contour of 7800 feet a current was formed at the Thistle Creek narrows, and two separate lakes resulted, with a short river between. The lower lake, covering Hayden Valley we may provisionally call Hayden Lake. The river at the narrows had glacial drift only to work on and was competent to cut this out widely as Hayden Lake level followed the lowering brow of the falls.

The problem was made more complex when the river discovered another wall of firm rhyolite at the site of the Upper Fall. This wall is much thicker than the lower one, and the process of cutting is proportionally slower. It was the lowering of this barrier which determined the lowering of Hayden Lake level. When the wall was cut somewhat below the 7700-foot contour, Hayden Lake was drained, and this has only very recently been accomplished, as is shown by the flat and sinuous course of Trout Creek.

The wearing down of the barrier at the Upper Fall has always lagged behind that of the lower. It could not be touched at all, until the lower barrier was reduced below its level, and the height of the Upper Fall has always been limited at its lower level, by the brow of the Lower Fall. The Upper Fall has increased in height almost uniformly with the decrease in height of the Lower Fall, and it is plain to be seen, that when the Lower Fall has finally sawed thru its barrier, the river will carry the canyon gradient back to the Upper Fall which will then be perhaps four hundred feet high.

With the lowering of these two barriers, other barriers were uncovered in the path of the stream above. The most important of these is a ridge of firm rhyolite in the bottom of the Thistle Creek narrows. This became a large factor in the history of the Yellowstone Lake, when in the cutting of the canyon at this point, this firm rhyolite was reached, at a level about sixty feet above the present lake. The lake level since then has waited on the lowering of this one barrier. It is the only barrier which now determines the lake level, altho it seems plausible that in earlier stages, a barrier at Mud Geyser, and perhaps even the Upper Fall barrier, were agents also in maintaining the lake at the sixty-foot terrace, the action on each barrier being much deferred by the lack of gradient due to the former higher elevation of these lower barriers.

This is the postglacial history of Yellowstone Lake and Canyon as it may be read from the data in hand. The whole great lake, with its drainage basin of about fifteen hundred square miles, was captured by the little Sulfur Creek canyon, taken bodily from the Snake River and the Pacific slope, and added to the Lamar River and the Atlantic slope. And the volume of water in the captive stream was so great as to dominate the lower valley of the Lamar, and reduce that older stream to the rank of a minor tributary.

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THE FAUNA OF THE DEVONIAN FORMATION AT MILWAUKEE, WISCONSIN

THE best, and until recently, the only known area of Devonian rocks in Wisconsin lies immediately north of Milwaukee and furnishes the Milwaukee hydraulic cement of commerce. This rock, in the localities where it is exposed, is a limestone, rich in magnesia, alumina, iron and silica. The best known exposure is in the valley of the Milwaukee River, about half a mile north of the present city limits. At this point many acres of the rock are accessible, forming the bed of the river, and stretching away on either side under alluvial and drift deposits, the latter of which constantly increase in thickness with the distance from the river. The formation is here about twenty five feet in thickness. Its surface may be thirty feet above the level of the lake, which lies a mile and a half to the east. There is a slight dip towards the southeast. The formation rests upon a dark, porous limestone supposed to be of Lower Helderberg age, without fossils. Three miles further north, at the edge of Lake Michigan, is an outcrop which rises slightly above the water level, and is about twenty feet thick. A shaft sunk at this place discloses layers corresponding to those of the lower twenty feet of the quarry on the river. Five miles north of the latter and about three miles further west there is a third exposure in a railway cut, at a considerable height above the river which flows near by; but the deep drift in the neighborhood of the cut has prevented any determination of the extent of the formation in this locality.

Within the past five years it has been found necessary to make additional provision for the city's water supply. In carrying out this provision a shaft was sunk to a depth of one hundred and thirty feet at the edge of the beach at the head of North Avenue, and from the bottom of this shaft a tunnel was bored extending out thirty-two hundred feet under the lake. As a preliminary to this undertaking test bores were made at a num-

ber of points. One of these, at a point very near the place where the shaft was finally sunk, revealed the following section, as shown by the records of the City Engineer's office. At the depth of forty two feet below water level, black shale was found, underlying strata of sand, gravel, and red and blue clay; at fifty seven feet, "soapstone;" at ninety seven feet, cement rock; at one hundred and seven feet, "soapstone" again; at one hundred and thirty-eight feet, "brownstone and lime rock." The "brownstone and lime rock" was not penetrated to any depth and it is not possible, perhaps, to assert positively what it was; but it is believed to be the same as the Lower Helderberg rock underlying the cement rock on the river.

The material taken from the new intake shaft and tunnel was dumped indiscriminately upon the beach. It has since been spread out, covered with soil, planted with grass and trees and made into a park. It was impossible, for the most part, to sort out the different components of the mass, or to determine except in a general way their original order of superposition. Cement rock and "soapstone" were mingled with each other and are alike disintegrating and turning to clay. The "soapstone" is a lumpy, nodular shale of a greenish-gray color, soft, when wet, hardening into something very like rock when dry, and turning very rapidly to clay under exposure to the rain and air. It strongly resembles some layers of the cement quarry rock, whose lowest and highest layers possess much the same qualities. Portions of the soapstone carry fossils in an excellent state of preservation, of the same species, for the most part, as those found at the quarry on the river. Mixed in with the "soapstone" are very hard layers, from one to four inches in thickness, largely composed of shells of *Chonetes scitulus* Hall, of a gibbous form, associated with *Tentaculites bellulus* Hall. The same form of *Chonetes* is also found amid the softer material in the dump and in the lower division of the quarry. The *Tentaculites* is also found at the cement quarry, but not so abundantly. A distinctly flatter variety of the same species of *Chonetes* is found in other portions of the "soapstone," and in the upper layers of the quarry.

Finely preserved shells of *Spirifer eurytcines* Owen, *S. asper* Hall, and *Atrypa reticularis* L., the latter with coarse plications, are found in the "soapstone" and in the upper layers at the quarry. Other portions of the "soapstone" are almost, or wholly, devoid of fossils, and in this they resemble some of the softer layers near the bottom of the quarry.

In the mass dumped on the beach were found some large stones, having the appearance of bowlders, composed of hard rock similar in color to the harder cement rock, but traversed by very hard white seams of a siliceous character. These seams are full of fossils, most of which are also found at the quarry. Such are *Chonetes scitulus* Hall, of the gibbous variety, *Spirifer subvaricosus* H. & Wh., *Palaeoneilo fecunda* Hall, and many others. Associated with these, however, are a number of gastropods, which give a distinctive character to the fauna of these seams; gastropods, with the exception of *Platyceras*, being very rare at the quarry. Among the gastropods of the white seams are *Bellerophon* near *pelops* Hall, and species of Pleurotomaria, Cyclonema and Loxonema.

The black shale, mentioned above as the first rock formation penetrated by the intake shaft, is quite distinct from the other materials dumped on the beach. Pieces of it exhibit glacial scratches. Its only fossils are two or three species of *Lingula*. Certain layers are firm and smooth-grained; others are extremely fissile, splitting into thin, rough laminae. There is also a greenish shale, whose exact place in the series is not ascertainable, also carrying species of Lingula. These shales are not found anywhere else in place in the state, though small rounded pieces are not uncommon in the drift. They seem to have given way everywhere else under the erosive action of the glaciers.

The rock at the cement quarry on the river comprises two main subdivisions distinguished, to some extent, by differences in their fossils, but still more noticeably by the different states of preservation in which their fossils are found. The lower subdivision is twenty-one feet in thickness. Fossils are abundant in this division, but principally in the form of casts and

impressions. Almost the only ones which are well preserved are specimens of *Lingula*, *Orbiculoidea* and *Conularia;* the plates, scales and teeth of fishes; and some plant remains in carbonized form. At the top of this section is a very hard layer about six feet in thickness, containing cavities lined with crystals of calcite and pyrite. This layer is very rich in fossils, very few forms being absent from it which are found in any part of the quarry; and it is especially distinguished by the multitude of its cephalopod and fish remains. The layers below this one are softer, some of them very soft indeed, and are on the whole less rich in fossils; but the surfaces of some of the lower layers are covered with pyritized shells of brachiopods, mainly *Chonetes scitulus* Hall, of the gibbous form, and *Delthyris consobrina* D'Orb.

The upper subdivision comprises the upper four feet of the quarry. Its surface has been smoothed by glacial action. Most of its fossils are found as casts in the section below, but here the shells are often preserved. Much of the rock of this division is of a lumpy, nodular character, and suffers rapid disintegration under atmospheric influences, the fossils weathering out.

These two sections, at the lake and at the river, are not precisely alike but are easily correlated with each other. The entire series of Milwaukee Devonian rocks may therefore be conveniently subdivided as follows, the section at the water tunnel being designated A, and the section at the cement quarries B.

A 4. The Lingula-bearing shales.

A 3. That portion of the "soapstone" carrying shells of *Spirifer curyteines* Owen, *S. asper* Hall, and *Atrypa reticularis* L., and the flat variety of *Chonetes scitulus* Hall; being the upper "soapstone" of the City Engineer's section.

A 2. This includes the thin hard layers so rich in specimens of the gibbous variety of *Chonetes scitulus* Hall, and *Tentaculites bellulus* Hall. It also includes portions of "soapstone," probably the lower "soapstone" of the City Engineer's section, containing the same variety of *C. scitulus* Hall, and *Conularia*. Its relations seem to be with subdivision B 1 of the quarry rock.

A 1. This consists of the thin white seams, whose relations are not definitely known.

B 2. The upper four feet of the quarry rock, corresponding with A 3.

B 1. The lower twenty-one feet of the quarry rock, including the very hard six-foot layer and several softer and less fossiliferous ones. This corresponds with A 2.

Very likely subdivision B 1, at the cement quarry, could be still further subdivided, the exceedingly hard layer at the top being especially worthy of a place by itself. It is sufficient, however, at present to say that this layer probably carries all the fossils of the layers below it except the plants — which come from further down — most of those above, and in addition a large number of fossils peculiar to itself. Among the latter are most of the fishes, most of the cephalopods, a few brachiopods and many pelecypods.

In the following table an attempt has been made to bring together the fossils of the several subdivisions for purposes of comparison. The lists are not exhaustive. Even at the cement quarry, which has been the most thoroughly examined, new species are occasionally found. The faunas of the shale and "soapstone" are less perfectly known, owing to the limited opportunity afforded for their study. Yet the formation has already furnished in the neighborhood of two hundred species, a remarkably rich collection from so limited a territory.

The determinations of species are in some cases provisional. The specimens of *Chonetes* and *Spirifer* have been submitted to Professor R. P. Whitfield and Mr. Charles Schuchert. The fish remains have been identified by Dr. C. R. Eastman and the crinoids by Mr. Stuart Weller. In other instances some of the names may have to be changed. Some of the species are new and have not yet received names.

It will be noticed that some species which are mentioned in the *Geology of Wisconsin* as coming from this formation are not contained in this list. Among them are *Chonetes coronatus* Conrad; *Productella spinulicosta* Hall and *Trematospira hirsuta*

Hall, all of which were probably determined from imperfect casts, or may have been taken from erratic blocks wrongly supposed to have been derived from this formation. Others, like *Spirifer granuliferus* Hall, *S. audaculus* Conrad, *S. angustus* Hall, and *S. euryteines*, var. *fornaculus* Hall, were probably mistaken identifications, justified at the time, but based upon casts of *Spirifer euryteines* Owen, which here exhibits great variations of form. Shells of the last named species are rarely found at the quarry, and only in one or two places, not in the rock but in the soil above composed of disintegrated rock. They are quite abundant in the upper "soapstone" from the intake. It is not probable that any had been unearthed at the time of the publication of the *Geology of Wisconsin*. They are distinguished by clearly marked lines of fine striation.

The writers have not attempted the correlation of the Milwaukee fauna with the faunas of other localities, but leave that interesting task to more competent hands. The Spirifers of the list, however (*S. iowaensis* Owen = *S. pennatus* Owen; *S. asper* Hall; *S. euryteines* Owen = *S. parryanus* Hall = *S. capax* Hall; and *S. subvaricosus* H. & Wh.) show an obvious relation to certain Devonian faunas of Iowa. It is proper to state that the shell here identified as *S. subvaricosus* H. & Wh. was by Mr. Schuchert considered to be a primitive form of *S. bimesialis* H., another Iowa species. Professor Whitfield, however, considers the identification as *S. subvaricosus* to be correct. Specimens of the shell from B 2, in which the beak has been ground down, seem to show a median septum. So do the casts in B. The latter, however, do not generally show the strong plication of fold and sinus, and such have been identified as *Delthyris consobrina*, D'Orb. (= *S. ziczac* Hall.) There is in the list a little *Rhynchonella*, identified as *R. contracta*, var. *saxatilis* Hall, which, if properly named, belongs also to the Rockford and High Point faunas. The Milwaukee specimens of *Schizophoria striatula* Schl. (= *Orthis impressa* Hall) are a form with a wide and not very deep sinus. Occasional forms are found resembling *Schizophoria tulliensis* Vanuxem, and *S. macfarlani* Meek.

A partial correlation of the fish remains has been furnished us by Professor Eastman. It is as follows:

Dinichthys pustulosus, Eastman — Hamilton Group of Iowa, Illinois and New York; Upper Devonian of Iowa.

D. tuberculatus, Newberry — Chemung Group of Pennsylvania; Upper Devonian of Belgium.

Ptyctodus calceolus, N. & W.—Hamilton Group of Iowa, Illinois, Missouri, Manitoba; Upper Devonian of Iowa.

Heteracanthus uddeni, Lindahl — Hamilton Group, Buffalo, Ia.

Onychodus sigmoides, Newberry — Corniferous Group of Ohio and New York; Chemung Group, Delaware county, N. Y.

Acantholepis fragilis, Newberry — Corniferous of Ohio & New York.

Sphenophorus, sp. — Chemung Group of Pennsylvania (*S. lilleyi* Newb.)

NOTE.—In the following tables the position of the various species in the different subdivisions is indicated according to their relative abundance by the letter A, abundant; C, common; O, occasional; R, rare.

FAUNA OF THE MILWAUKEE DEVONIAN FORMATION

	A_4	A_3	A_2	A_1	B_2	B_1
PISCES						
Acantholepis fragilis Newb. (=*A. pustulosa* Newb.)					Occasional small fish remains	R
Cladodus sp.						R
Dinichthys pustulosus Eastman						O
D. tuberculatus Newberry						R
D. sp.						R
Heteracanthus politus Newberry						R
H. uddeni Lindahl						R
Onychodus sigmoides Newberry						R
Palaeomylus greenei Newberry						O
Phlyctaenacanthus telleri Eastman						R
Ptyctodus calceolus N. & W.						R
P. ferox Eastman						R
Rhynchodus excavatus Newberry						R
Sphenophorus sp.						R
Titanichthys sp.						R
Scales of fishes, of undetermined species						O
CRUSTACEA						
Echinocaris (=*Ceraliocaris*) sp.						R
Phacops rana Green					C	O
Proëtus sp.					R	R
P. sp.				R		
CEPHALOPODA						
Gomphoceras breviposticum Whitfield						O
G. fusiformae Whitfield						O
G., at least ten other species, large and small, including so-called "Horses' Hoofs," all from B_1						
Goniatites sp.						R
Gyroceras eryx Hall						C
G., three or four other species						R
Orthoceras, large, like *O. bebryx* Hall						R
O., very slender				R		
O., one or two other species					R	R
PTEROPODA						
Conularia sp.		?	R		R	R
Hyolithes sp.				R	R	R
Tentaculites bellulus Hall			A	A		R
GASTROPODA						
Bellerophon, near *pelops* Hall						
Callonema sp.				R		
Cyclonema sp.					R	
Loxonema sp.				R		
Murchisonia sp., minute, preserved in pyrites						R
M. sp., large					R	
Platyceras auriculatum Hall					R	
P. carinatum Hall					R	
P. erectum Hall					R	
P., two other species					R	
Pleurotomaria, two or three species				R		

	A_4	A_3	A_2	A_1	B_2	B_1
PELECYPODA						
Actinopteria sp.				R		
A. sp.					R	R
Cimitaria elongata Conrad.						R
Clidophorus oblongus Hall.						R
Goniophora hamiltonensis Hall						R
Grammysia nodocostata Hall.			R			R
G. subarcuata H.						R
G. sp.						R
Leda, near *rostellata* Conrad.						R
Lyriopecten, near *interradiatus* Hall						R
Modiola precedens Hall.						R
Modiomorpha affinis Hall.						R
M. alta Conrad.						R
M. concentrica Conrad.					R	O
M. macilenta Hall.						R
M. mytiloides Hall.						R
M. ponderosa Hall.						R
M. quadrula Hall.						R
M. subulata Hall.						R
M. subulata var. *chemungensis* Hall.						R
Mytilarca umbonata Hall						R
M. (*Plethomytilus*) *oviformis* Conrad.						R
Nucula corbuliformis Hall.						O
N. randalli Hall.						O
Nuculites oblongatus Conrad.				R		
Palaeoneilo brevis Hall.			R			
P. constricta Conrad.				O	O	C
P. elongata Hall.						R
P. emarginata Hall.				R		R
P. fecunda Hall.			O	O	O	R
P. plana? Hall				R		
P. sp.			R			
Paracyclas elliptica Hall.				R		
P. tenuis Hall.						R
Pterinopecten, near *intermedius* Hall			R			
Sphenotus, near *cuneatus* Conrad.						R
S., near *clavulus* Hall.						R
Many other species of Pelecypoda, imperfectly preserved in B_1						
BRACHIOPODA						
Athyris fultonensis Swallow.			R		A	R
A. sp.					R	
Atrypa hystrix, var. *occidentalis* Hall						O
A. reticularis L.			A	O	A	A
A. spinosa Hall.						R
Camarotoechia near *sappho* Hall.						R
C. contracta, var. *saxatilis* Hall,			R	R	R	R
Chonetes scitulus Hall—flat variety.			O		A	
C. scitulus Hall—gibbous variety.				A		C
C. vicinus Castelnau (=*C. deflectus* Hall)						R
Craniella hamiltoniae Hall.						R

	A_4	A_3	A_2	A_1	B_2	B_1
Cyrtina curvilineata White					R	
C. hamiltonensis Hall		R			A	R
C. hamiltonensis var. *recta* Hall		R			C	R
Delthyris consobrina D'Orbigny				C		A
Dielasma calvini H. & Wh.					C	
Eunella lincklaeni Hall					O	
Liorhynchus kelloggi Hall						O
L. sp.						R
L. sp.		R				
Lingula complanata Williams	R					
L. maida Hall						R
L. melie Hall	C					
L. spatulata Vanuxem	R					R
L. sp.						R
Lingulella paliformis Hall						R
Orbiculoidea lodiensis Hall		O			O	O
O. lodiensis var. *media* Hall		O			O	O
O. marginalis Whitfield		O			O	O
O. two other species						R
Orthis sp.					R	
Orthothetes chemungensis var. *arctistriata* Hall		O		R	O	O
Pentamerella, two species						R
Pholidostrophia iowaensis Owen		O			A	R
Schizophoria macfarlani Meek					R	
S. striatula Schlotheim		R			A	A
S. tulliensis Vanuxem					R	R
Spirifer asper Hall		C		R	O	O
S., near *Euryteines* Owen		C	R	R	O	A
S. iowaensis Owen					R	O
S. pennatus Atwater					R	R
S. pennatus var. *posterus* Hall						R
S. subvaricosus H. & Wh.				O	A	O
S. sp.						O
Stropheodonta demissa Conrad		O	R	R	A	A
S. perplana Conrad		O	R	R	A	A
S. sp.					O	O
Terebratula, one or two species					R	
BRYOZOA — including Monticuliporoids						
Aulopora, two species, free growing					O	
A., one or two species on shells of Brachiopods					O	
Fenestella sp.						O
F. sp.						R
F. sp.					R	
Hederella, one or two species on shells of Brachiopods					C	
Hernodia humifusa Hall, on Gomphoceras						R
Reptaria stolonifera Rolle, on Gomphoceras						R
Stictopora, one or two species					A	
Stomatopora sp., on shells of Brachiopods						R
Of Monticuliporoids there are several different genera and species; with simple thin-walled cells; with thick-walled cells; with intermediate mesopores; massive, dendritic, and laminar — In Section A_2 and B_2.						

	A_4	A_3	A_2	A_1	B_2	B_1
ANNELIDA						
Cornulites sp.					R	
Spirorbis, one or two species, on Brachipods					R	R
ECHINODERMATA						
Melocrinus milwaukensis, Weller					R	
M. milwaukensis var. *rotundatus* Weller					R	
M. nodosus Hall					R	
M. nodosus var. *spinosus* Weller			R		R	
M. subglobosus Weller					R	
M. sp.					R	
Pentremitidea filosa Whiteaves					R	
P. milwaukensis Weller					R	
Taxocrinus sp.					R	
Crinoid stems of several sorts					C	
COELENTERATA						
Favosites sp.						R
Heliophyllum halli Ed. & H.						R
Zaphrentis, one or two species						R
SPONGIDA						
Sp. ?						R
PLANTAE						
About a dozen carbonized forms of land plants of several genera; some threadlike, or with thread-like branches; the largest over four feet long and as much as five inches wide; all somewhat flattened; mainly in the softer layers of B_1.						
Also several species of fucoids, in all layers of both sections.						

As we go to press, Dr. C. R. Eastman, furnishes the following note on the fossil fishes mentioned in the foregoing article:

ELASMOBRANCHS

Ptyctodus calceolus N. & W. (Tritors only).

P. ferox East. (Complete dental plates, upper and lower jaws).

Rhynchodus excavatus Newb. (Complete dental plates, upper and lower jaws).

Palaeomylus greenei (Newb.). (Complete dental plates, upper and lower jaws).

Cladodus sp. nov. (Detached teeth).

Heteracanthus politus Newb. (Spines).

H. uddeni Lindahl. (Spines).

"PLACODERMS" (including *Arthrodira*)

Acantholepis fragilis Newb. (=*A. pustulosa* Newb.). Fragmentary spines).

Phlyctaenacanthus telleri Eastm. (Fragmentary spines).

Dinichthys tuberculatus Newb. (Fragments of dermal armor).

D. pustulosus Eastm. (Crania, dorsal and ventral plates; also portions of the dentition).

Large, thin plates belonging to two as yet unknown Dinichthyids, probably *Dinichthys* or possibly akin to *Titanichthys*.

Sphenophorus sp. nov. (Fragments of dermal plates).

CROSSOPTERYGIANS

Onychodus sp. (Clavicle and other plates very suggestive of *O. sigmoides* Newb., but as yet no teeth nor scales, sufficient to prove specific identity).

Several varieties of scales and other fragments.

CHARLES E. MONROE.
EDGAR E. TELLER.

MILWAUKEE, WIS.
February 16, 1899.

THE PETROGRAPHICAL PROVINCE OF ESSEX COUNTY, MASS. IV.

BASIC DIKES

By far the greater part of the dikes of this region are dense black rocks, evidently very basic in character. The majority of these are diabases of various kinds, only a few not belonging to this ever-present family and representing more unusual types. However, these basic dikes have been so far but little investigated, but it will not be amiss to describe the specimens in my possession.

Camptonitic dikes.— Cutting the foyaite of Salem Neck and, according to Sears, the "augite-syenite" of Coney Island in Salem Harbor are dikes of dense, black, finely crystalline rock without phenocrysts, and composed essentially of hornblende, less augite, and plagioclase. These rocks are unlike typical camptonites since there are no large and abundant ferromagnesian phenocrysts, and alumina is rather high. In certain respects they seem to be allied to the proterobases. They are provisionally classed with the camptonites for various reasons, among which may be mentioned their connection with foyaite, certain features of their chemical and mineralogical composition, and their resemblance to camptonitic rocks from localities in Maine, New Hampshire, Vermont, and Norway. It is, by the way, a somewhat remarkable fact that no typical camptonites or monchiquites have yet been observed in the region.

Under the microscope these rocks are holocrystalline, and in fresh specimens have a structure approaching the ophitic, though the colored components are, as a rule, more automorphic than is the case when this structure is typically developed. The following minerals are present: much hornblende, less pyroxene, occasional olivine, plagioclase, a little orthoclase, some magnetite, and rare apatite. Neither biotite nor titanite were seen.

The hornblende forms either stout prismatic crystals or irregular grains. In the latter case it is generally, but not constantly, later than the plagioclase and interstitial to some extent. It is a peculiar yellow-brown, closely similar to the barkevikite of the Norway rocks, as shown by comparison with sections of these. The pleochroism is strong: for the axis nearest *c*, dark yellow-brown; parallel to axis *b*, about the same, nearly parallel to axis *a*, light greenish-yellow. The depth of the color rendered the determination of the axes of elasticity uncertain. The extinction is rather high, about 20 degrees. This hornblende frequently occurs as a primary border about augite and magnetite, as in the hyperitic diorites. The pyroxene, which forms irregular grains or occasionally large porphyritic crystals, is colorless, with sometimes a tinge of green or violet. Olivine is rare, except in one specimen from Coney Island, in large corroded colorless grains. They are usually altered at the borders to a black granular substance, and are occasionally serpentinized. The plagioclase, which occurs in long lath-shaped sections, tabular parallel to *b* (010), as well as in anhedra, is highly twinned. Measurements by Michel-Lévy's method indicate a labradorite with the composition Ab_3 An_4, though some are nearer the andesines. Small colorless interstitial grains with low refractive index are referred to orthoclase.

	I	II	III	IV
SiO_2	46.59	48.98	45.20	48.08
TiO_2	1.41	0.56	0.68	2.57
Al_2O_3	17.55	17.76	17.12	16.95
Fe_2O_3	1.68	2.14	5.98	4.78
FeO	10.46	6.52	6.55	7.60
MnO	.....	.....	.....	trace
MgO	7.76	2.09	5.29	5.51
CaO	10.64	8.36	7.89	7.79
Na_2O	3.31	6.77	4.23	3.37
K_2O	0.72	2.08	2.31	1.42
H_2O (110°)	0.10	.....	.....	.....
H_2O (ignit.)	0.07	4.50	5.35	0.80
P_2O_5	.....	.....	.....	0.63
CO_2	....	0.82	.....	.....
	100.29	100.58	100.60	99.48

I. Camptonite (?). Salem Neck. H. S. Washington anal.

II. "Diorite-Porphyrite." St. Johns, N. B. W. D. Matthew, Trans. N. Y. Acad. Sci., Vol. XIV, p. 213, 1895.

III. Camptonite. Portland, Me. E. C. E. Lord, Amer. Geol., Vol. XXII, p. 344, 1898.

IV. Bronzite-Kersantite. Hovland, Norway. Brögger, op. cit., Vol. III, p. 75.

An analysis of a fresh specimen from a narrow dike cutting foyaite on Salem Neck is given in I. The low titanium oxide accords with the absence of titanite and the character of the pyroxene. It is evident that alumina largely replaces ferric oxide in the ferro-magnesian minerals. This is a feature of barkevikite as shown by Flink's analysis,[1] and some of the hornblendes whose composition has been calculated by Brögger,[2] as well as of the hornblende of Hawes's camptonite.[3]

As was stated above very similar rocks have been observed in New England. For instance, it resembles a specimen from Livermore Falls, near Campton, N. H., for which I am indebted to Professor Pirsson. This, however, does not carry hornblende phenocrysts, and is also like some of the camptonites of Lake Champlain.[4] Hobbs[5] also describes similar rocks as augite-diorite, occurring in connection with the diabase of Medford, Mass. A nearly identical rock is described by W. D. Matthew[6] as occurring in dikes near St. Johns, N. B. The hornblende is also apparently barkevikite, and an analysis of this rock is given in II. Very recently E. C. E. Lord[7] has described a dike of camptonite from Portland, Me., which is closely allied, and the analysis of which is given in III. These two contain considerably more alkalies than those described in this paper. These

[1] DANA, A System of Mineralogy, New York, 1892, p. 403.

[2] BRÖGGER, op. cit., III, p. 110.

[3] LORD, Amer. Geol., Vol. XXII, p. 343, 1898; also, ROSENBUSCH, Elem. Gesteinlehre, p. 234, No. 1, 1898.

[4] KEMP and MARSTERS, Bull. U. S. G. S., No. 107, p. 29, 1893.

[5] W. H. HOBBS, Bull. Mus. Comp. Zoöl., Vol. XVI, p. 10, 1888.

[6] W. D. MATTHEW, Trans. N. Y. Acad. Sci., Vol. XIV, p. 210, 1895.

[7] E. C. E. LORD, Amer. Geol., Vol. XXII, p. 342, 1898. *Cf.* KEMP, dikes near Kennebunkport, Me., Amer. Geol., p. 129, 1890.

are all decidedly more acid than the usual camptonites, and carry higher alumina. Chemically they show marked affinity with certain kersantites from Norway described by Brögger,[1] one of his analyses being given in IV.

Vogesitic dikes.—A few dikes were found of a dark rock composed of hornblende, augite, and biotite, but with alkali-feldspar very largely predominating over plagioclase. A little quartz is also apt to be present, which is apparently primary. These rocks then have the mineralogical composition of vogesite or minette, apart from the presence of quartz, and are provisionally put here, since no chemical analysis has yet been made of them.

As an example there may described a dike from Davis Neck, Cape Ann, which is almost black, fine-grained, and compact, and with small shining black phenocrysts of ferro-magnesian minerals. Of these the pyroxene is colorless or very pale green, the hornblende of a light bluish-green, both in irregular grains, and the biotite in thick plates of a light brown color and highly pleochroic. These minerals are not distributed evenly, but occur in streaks in which one or the other predominates. The interstitial groundmass is of colorless granular alkali-feldspar without plagioclase or quartz. A little magnetite is present but no apatite.

Diabase.—Dikes of dense black rock, which may be grouped under this heading, are very abundant. They far outnumber all the other dikes put together, but as is usually the case they are rather monotonous in character, as well as nearly always more or less altered. Shaler's map of Cape Ann will show their abundance, and to his paper[2] the reader is referred for a full discussion of their occurrence, dip and strike, and other features. As regards their relations to the other rocks it may be noted that they cut, and are hence later than, all the other types.

They vary from fine-grained to aphanitic, the usual change in texture from center to border being often seen. In general they are not as coarse-grained as the sheets, dikes, and flows of

[1] BRÖGGER, op. cit., Vol. III, p. 71

[2] SHALER, Ninth Ann. Rep. U. S. G. S., 1889.

similar rock which are met with in such abundance in the Triassic of Connecticut and New Jersey, this being due to their having cooled as much smaller bodies. Amygdaloidal structure is very rare. They may be divided roughly into two main groups, the ophitic and basaltic, though these merge into each other, and frequently the center of a dike is ophitic while its border is basaltic.

The ophitic diabases present the usual features. The feldspar, in stout plates, is chiefly a well-twinned plagioclase, with extinction angles corresponding to a labradorite of about the composition $Ab_1\ An_3$. It is often cloudy or epidotized through alteration. A little orthoclase seems to be present. The augite, which is seldom automorphic, is pale violet-gray in thin sections, and is frequently uralitized, often to such an extent that little of the original mineral remains. Magnetite is quite common in large grains, often showing octahedral outlines, and has a strong tendency to stout skeleton growths. An interesting case of this is seen in a dike-cutting rhyolite on Marblehead Neck where the magnetite skeletons assume the form of small stout crosses with thickened ends, or with their ends joined by the sides of a hollow square, the cross in this case forming the diagonals. These growths are analogous to those of leucite in certain leucitites from Montana[1] and Italy.[2] The magnetites are frequently accompanied or surrounded by brown, apparently secondary, biotite, even in the freshest specimens. With this exception neither biotite nor hornblende is to be seen, nor was olivine observed. Apatite is not abundant.

The basaltic diabases are black and aphanitic, without megascopic phenocrysts. They show in thin sections laths of clear labradorite and some crystals of augite in a mixture of augite grains, small labradorite laths and magnetite with considerable light-brown glass base. The magnetite very frequently assumes delicate arborescent forms, branching at right angles, which are very pretty and characteristic. In a small apophysis of the

[1] L. V. PIRSSON, Bearpaw Mountains, Am. Jour. Sci. (4), Vol. II, p. 145, 1896.

[2] H. S. WASHINGTON, Bolsena, JOUR. GEOL., Vol. IV, p. 557, 1896.

ophitic Dike 73, at Bemo's Ledge, Cape Ann, magnetite is wanting and the brown glass abundant. Flow structure is sometimes seen. These varieties closely resemble many normal olivine-free basalts.

	I	II	III	IV	V
SiO_2	47.12	48.75	51.78	51.36	36.85
TiO_2	3.27	0.99	1.41	....	....
Al_2O_3	14.43	17.97	12.79	16.25	15.46
Fe_2O_3	3.33	0.41	3.59	2.14	....
FeO	11.71	13.62	8.25	8.24	17.50
MnO	....	0.91	0.44	0.09	....
MgO	6.05	3.39	7.63	7.97	5.60
CaO	9.63	8.82	10.70	10.27	15.73
Na_2O	2.58	1.63	2.14	1.54	....
K_2O	1.11	2.40	0.39	1.06	....
H_2O (110°)	0.28	....	....	....	....
H_2O (ignit.)	0.34	0.60	0.63	1.33	....
P_2O_5	....	0.68	0.14	....	....
	99.85	100.17	99.89	100.28	91.14

I. Diabase. Rockport. H. S. Washington anal.

II. Diabase. Medford, Mass. Sweetser anal. Traces of CO_2 and FeS_2. Probably Al_2O_3 too high and MgO too low. Hobbs, Bull. Mus. Comp. Zoöl. XVI, p. 9, 1888.

III. Diabase. West Rock, New Haven, Conn. G. W. Hawes anal. Proc. U. S. Nat. Mus., IV, p. 132, 1882.

IV. Diabase. Watchung Mountain, Orange, N. J. L. G. Eakins anal. Bull. 148 U. S. Geol. Surv., p. 80, 1897.

V. Diabase (?). Marblehead Neck. R. Pearce, Proc. Colo. Sci. Soc., IV, 1893.

For purposes of analysis the freshest specimen was chosen from a dike of ophitic diabase cutting the granite in the large quarry pit at Rockport. It calls for little remark, except that the alumina is rather low and the titanium oxide is high. It resembles analyses of other diabases from Massachusetts, one of which is given (II), but is more basic than the "traps" of Connecticut and New Jersey (III and IV). For purposes of completeness a partial analysis is given (V) of a so-called diabase dike, briefly noticed by R. Pearce, from Marblehead Neck. It is not very satisfactory. The silica is abnormally low, lime high,

as well as iron oxides, and the large loss is difficult to account for, assuming that the analysis is correct. There cannot be enough alkalies to make up the deficiency, and it is probably largely water. The rock is possibly decomposed, since Merrill[1] has shown that diabase loses silica through decomposition. It is also possible that it is a monchiquite.

Labradorite-porphyry.—Closely related to the diabases are a few dikes distinguished by the presence of prominent phenocrysts of plagioclase in a black, fine-grained groundmass. The best example is Shaler's Dike 175, which cuts across the quarry pit at Pigeon Cove. It is eighteen feet in width, with a strike of N. 9° W.[2] The phenocrysts here are very large and automorphic. A similar dike cuts the tinguaite at Pickard's Point, in which the phenocrysts at the center are even larger, attaining diameters of more than six inches; toward the borders they are smaller, and at the contact very small.

The groundmass of these rocks is like that of the diabases, though an ophitic structure is less often developed. It is composed of labradorite, augite, and magnetite, primarily, but in every case is more or less altered, so that secondary hornblende and biotite with chlorite, etc., are present in abundance, and any analysis would be unsatisfactory.

EXTRUSIVE ROCKS

Rhyolite.—The only flow rocks found in Essex county are rhyolites, which occur in large sheets about Lynn, Newbury, Old Town, and Marblehead Neck. The last is the only locality which I have visited. This is not the place to dwell upon the discussions which have taken place as to the origin of these rocks, between Sterry Hunt and his followers, who tried to show that these, as well as all the igneous rocks of the region, were altered sediments, and the other party, headed by Wadsworth and Diller, who finally overthrew this view and proved conclusively that they are typical volcanic flows. For particulars of this discus-

[1] G. P. MERRILL, Bull. Am. Geol. Soc., Vol. VII, p. 349, 1896.

[2] SHALER, op. cit., pp. 592, 607.

sion the reader is referred to "The Azoic System," by Whitney and Wadsworth.[1]

These rhyolites are dense, black, aphanitic rocks, with a dull or subvitreous luster and subconchoidal to even fracture. Small, white feldspar phenocrysts are scattered through this black groundmass. A banded or flow-structure is often noticeable, and is especially well brought out on weathered surfaces.

Under the microscope these rocks present a somewhat monotonous appearance. The feldspar phenocrysts are usually quite sharply automorphic, less often fragmentary. Most of these are of orthoclase, or rather soda-orthoclase, while a few show the twinning lamellæ and extinction angles of oligoclase-albite. They are all somewhat decomposed so that optical examination is unsatisfactory.

The groundmass is composed of alkali-feldspar with some finely granular quartz, very small shreds and grains of pale greenish pyroxene and a little magnetite. Glass is present in some specimens, but in the majority of cases it has been devitrified, and its former presence is difficult to determine with certainty. Some of the specimens were apparently primarily holocrystalline. Flow-structure is observed, but is not as marked as one would be led to expect from some of the weathered specimens. These rhyolites, it may be added, are accompanied by ash beds and breccias.

I owe to Mr. Sears a specimen of a dike rock much like these rhyolites, which cuts the diorite on the south shore of Salem harbor, west of Marblehead. It shows flesh-colored feldspar and colorless quartz phenocrysts in an aphanitic groundmass. In thin section it resembles the rhyolites, but is distinguished by the abundance and sharp outlines of the quartz phenocrysts and the presence of numerous spherulites in the devitrified groundmass, which exhibit a black cross between crossed nicols.

[1] Bull. Mus. Comp. Zoöl., Vol. VII, Cambridge, 1884, pp. 331–565. *Cf.* also G. H. WILLIAMS, JOUR. GEOL., Vol. II, p. 24, 1894.

SiO_2	70.64	MgO	0.52
TiO_2	0.90	CaO	1.24
Al_2O_3	15.34	Na_2O	5.23
Fe_2O_3	1.83	K_2O	3.55
FeO	1.10	H_2O (110°)	0.14
MnO	trace	H_2O (ignit.)	0.38
			100.87

Rhyolite. Northeast coast of Marblehead Neck. H. S. Washington anal.

For the analysis a typical specimen was chosen from the northeast coast of Marblehead Neck. As will be seen, these rocks are rather acid, and resemble the quartz-syenite-porphyry more than they do the aplite. The only point to be mentioned here is that soda is considerably higher than potash.

Keratophyr.—The last rock to be described is that by which this region is, perhaps, best known, which Rosenbusch[1] has taken as the type of his bostonites, and which Sears[2] has described as keratophyre. Accepting provisionally Rosenbusch's system of classification the choice of names depends on whether the rock occurs as a dike or a flow. Owing partly to the fact that the exposure is only visible at low tide the relations are somewhat difficult to make out. My observations were confirmatory of the views expressed by Wadsworth[3] and Sears[4] that the rock forms a flow and not a dike, overlying rhyolite and conglomerates. This being so, I think that the name bostonite is not justified in this case, and I prefer to retain Sear's name, keratophyr (rather than trachyte), on account of the large content of anorthoclase, even though this name is in several respects a very bad one.

My specimens come from Boden's Point, below Mr. Foster's house, and from below the Corinthian Yacht Club House. Although the rock has been described by Sears and Rosenbusch, a few words may be devoted to it. The freshest specimens are

[1] ROSENBUSCH, Tsch. Min. Pet. Mitth., Vol. XI, p. 447, 1890; Mikr. Phys., Vol. II, p. 467, 1896.

[2] SEARS, Bull. Mus., Comp. Zoöl., Vol. XVI. p. 167, 1890.

[3] WADSWORTH, Proc. Boston Soc. Nat. Hist., Vol. XXI, p. 288, 1881.

[4] SEARS, op. cit.

creamy white, weathering to brown, very fine-grained and with a dull luster, and a tendency to schistosity, which largely accounts for the earlier view that this was a sandstone. A few glistening white phenocrysts of anorthoclase are visible.

In thin section the phenocrysts show the characters described by Rosenbusch and Sears. The groundmass is trachytic with pronounced flow-structure, and is composed largely of small alkali-feldspar laths, these being generally clear. The interstitial matter is clear and colorless with low refractive index, partly isotropic and partly feebly doubly refracting. Some of it seems to be glass and some kaolinized feldspar. There is considerable "dust" and many small black and brown specks, the remains of former ferro-magnesian minerals, which, however, never were present in a large amount. Very few traces of these remain, only rare, small biotite flakes being seen. A little quartz is present, but is rare.

Two analyses of this keratophyr are given, one by myself and the other by Dr. Chatard, of the United States Geological Survey, for Mr. Sears. They resemble each other very well, though mine shows a little more silica. It will be noticed that they are not markedly different from the rhyolite, though in this lime is higher.

	I	II
SiO_2	71.40	70.23
TiO_2	....	0.03
Al_2O_3	14.76	15.00
Fe_2O_3	1.68	1.99
FeO	0.72	....
MnO	trace	0.24
MgO	0.55	0.38
CaO	0.10	0.33
Na_2O	4.79	4.98
K_2O	5.16	4.99
H_2O (110°)	....	0.91
H_2O (ignit.)	1.46	1.28
P_2O_5	....	0.06
	100.62	100.42

I. Keratophyr. Boden's Point, Marblehead Neck. H. S. Washington anal.

II. Keratophyr. Boden's Point, Marblehead Neck. T. Chatard anal. Sears, Bull. Mus. Comp. Zoöl., XVI, p. 170, 1890; also Bull. 148, U. S. Geol. Surv., p. 78, 1897.

HENRY S. WASHINGTON.

EDITORIAL

THE great success which has attended the application of photography to the determination of the positions and movements of stars may well stimulate geologists to attempt a similar application to earth movements. It is a not uncommon belief among mountaineers that peaks which were formerly not visible from certain points of view have recently come into sight, and conversely that points formerly in view have disappeared from sight. There is nothing incredible in this if warping is in active progress, and it would seem worthy of being put to the test of exact observation. It would not be difficult to take photographic panoramas from selected points of view, and to record with precision the positions of the camera, so that views could be taken from exactly the same points at subsequent dates. A comparison of such views would serve to show whether any appreciable warping of the crust is in progress or not. The effect of degradation on the one hand, and of snow accumulation, on the other, could easily be eliminated, and the influence of refraction might be avoided by taking the photographs in precisely similar conditions of atmosphere and light, or the proper correction could be made. As this method is probably applicable only to serrate alpine tracts, it is to be hoped that some of the geologists of those regions will interest themselves so far as to take and duly register a first series of photographs so that comparison may be made at some future time.

T. C. C.

THE doctrine of alternate quiesence and readjustment of the crust of the earth serves such a radical function in the interpretation of ancient peneplains, sea-shelves, and epicontinental seas, and in the elucidation of expansional, repressional, and provincial epochs of life evolution, that a precise conception of what

is understood by quiescence and readjustment may aid in the removal of doubts and objections, since some of these seem to be based on a rather too rigid and literal interpretation of the terms quiescence and readjustment and their synonyms. Like most terms which relate to the mutual relations of the sea and the land, or of the continental platforms and the abysmal basins, the term quiescent has a merely relative meaning. It does not necessarily signify an absence of absolute movement toward the center of the earth, but simply an absence of *differential* movement relative to other portions of the crust. If the whole crust sinks toward the earth's center at an equal rate in all its parts, the relations of the continental platforms and the abysmal basins remain essentially undisturbed and may be said to be quiescent. Such a shrinkage may theoretically reduce the capacities of the ocean basins just as it reduces the whole surface of the sphere, and this reduction of basin capacity may cause the sea to overlap the margin of the land in some degree. But this incursion of the sea, would, if appreciable, be justly regarded as only an incident of the quiescent stage. It would indeed be only one of several factors involved in that transgression of the sea which is so characteristic of quiescent stages. It is only when such a common sinking of the crust toward the center develops *differential* stresses of such magnitude as to require a notable warping, crumpling, or faulting of the crust that the relations of the continental platforms to the abysmal basins are seriously disturbed and the quiescent stage is replaced by one of readjustment. It is perhaps even necessary to regard such a common centripetal movement during the quiescent period as a necessary antecedent of the period of readjustment, for such a movement is perhaps necessary to develop the differential stresses out of which the readjustment springs. All objections therefore to the doctrine of periodic quiescence which are based upon the conception of the absence of centripetal motion should be set aside as based upon misconception. The only valid theoretical objections are those which apply to the conception of periods of *concordant* centripetal movement alternating with periods of *discordant* cen-

tripetal movement. The former are quiescent periods so far as the relations of platforms and basins are concerned, the latter are periods of readjustment. The dynamical conception involved in this view is somewhat radically different from that involved in the literal conception of quiescent periods as periods of no crustal movement at all.

In the accumulation of the general stresses which issue in general readjustments, local stresses of special intensity must almost necessarily be developed and these may reach such a degree of intensity as to lead to local readjustments. These local readjustments may result in the distribution of the stresses over wider areas, and these wider areas may in time yield and transmit the stresses to still broader fields until the stresses become general and reach such a degree of intensity as to issue in a general readjustment. Local readjustments in the form of local warpings and faultings may be incidents of the general quiescent stages, and like them may be essential antecedents of general readjustments involving the formation of mountain systems and similar pronounced phenomena.

T. C. C.

THE DUPLICATION OF GEOLOGIC FORMATION NAMES

THE custom of giving more or less local geographic names to geologic subdivisions has become so universal that we are even now duplicating the use of such names to a considerable extent. Geological literature is of too great bulk for the working geologist to attempt to ascertain whether or not names which he proposes to use have been preoccupied. To illustrate what the present system is leading to a few instances of some prominence will be cited.

In 1883 Hague described, in a report of the United States Geological Survey the Eureka quartzite, a subdivision of the Silurian in the Eureka district, Nevada. In 1891 Simonds and

Hopkins, in a report of the Arkansas Geological Survey, used the name Eureka shale for a supposed Devonian horizon; while in 1898 Haworth, in a report of the Kansas Geological Survey, proposes the name Eureka limestone as a subdivision of the Coal Measures.

In 1879 Peale, in the Eleventh Annual Report of the United States Geological and Geographical Survey of the Territories, employed the term Cache Valley group for a subdivision of the Pleistocene of Utah. Becker described in 1888 the Cache Lake beds of California, in Monograph XIII of the United States Geological Survey, and referred them to the Tertiary. In 1896 G. M. Dawson, in a report of the Canada Geological Survey, uses the name Cache Creek formation for a horizon of the Carboniferous to include strata described by Selwyn in 1872 as Upper and Lower Cache Creek beds.

In 1842–1846 Emmons, Vanuxem and Mather employed the term Erie division as a subdivision of the New York system. In the Ohio Geological Survey reports the Erie clay was used as a subdivision of the Pleistocene, and Erie shale was referred both to the Carboniferous and Devonian. In 1875 Lesley described, in a report of the Pennsylvania Geological Survey, the Erie shale, which he referred to the Silurian. In 1898 Haworth described the Erie limestone of the Coal Measures of Kansas. The above references are given merely to illustrate the confusion that is likely to arise from the use of new geographic terms if the literature is not carefully examined for previous use.

For the past eighteen months the writer has been engaged in preparing a card catalogue of geologic formation names, during such time as could be taken from other office and field work. This catalogue has already assumed considerable proportions, and is now being consulted by those geologists who are aware that such a work is being prosecuted. While preparing the annual bibliography of geological literature for 1898 the writer has found several instances of duplication of names that have become well established in geological nomenclature. It will

probably be a year or more before this catalogue can be published, and, in the meantime, to assist in avoiding such duplication, the writer offers to furnish geologists, who will correspond with him, such information as he possesses, regarding names which they propose to use as formation names.

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Reviews

Experimental Investigation of the Formation of Minerals in an Igneous Magma.[1] A review.

Professor Morozewicz has at length published in German the results of five years' elaborate experimentation on the synthesis of minerals and of volcanic rocks. This work is the most exhaustive of its kind since Fouqué and Lévy's epoch-making experiments, published in Paris in 1882. The wide scope and large scale of the experiments of Morozewicz, and the very complete chemical investigation of his products, together with carefully devised reference to the geological application, make this new work worthy of extended review and of careful study by geologists.

The motive of the experimenter was primarily to imitate, as nearly as possible, natural igneous magmas, and by fusion of carefully prepared chemical mixtures in a large glass furnace to produce crystalline masses in sufficient volume for isolation and chemical investigation of the component artificial minerals. The author lays stress upon the importance of more careful work in the chemistry of the silicates in mineralogy, and the chemistry of silicate mixtures or solutions in petrography. For the former the work of Lemberg and Thugutt is quoted as of primary importance, and for the latter Lagorio and Vogt have initiated methods of research that should be emulated for more complete understanding of the nature of igneous rocks. The work of Fouqué and M. Lévy was limited to microscopic investigation of the products of fusion in small platinum crucibles in the Fourquignon furnace. Morozewicz obtained the use of a corner in a large Siemens furnace, in a glass factory near Warsaw; the interior of this furnace is much of the time at white heat and continuously so for periods of weeks and months. The furnace is heated by a blast of carbonic monoxide mixed with air, and the temperature to which the crucibles were sub-

[1] Josef Morozewicz (Warsaw). Experimentelle Untresuchungen über die Bildung der Minerale im Magma. Tschermak's Mineralog. u. Petrogr. Mittheilungen, Bd. XVIII, H. 1–2–3, pp. 1–90 and 105–240, 8 Plates, 1898.

jected was estimated to vary from 1600° down to 500° C. Two openings, half a foot long each, were arranged in the side of the furnace so that crucibles could easily be inserted and removed. The temperature within the entrance chamber was much less than in the heart of the furnace, and by placing a crucible first in the innermost glow, then at the inner mouth of the chamber, and lastly, a short distance within the chamber, conditions of gradual cooling and crystallization could be brought about. From day to day at certain periods there were variations in the temperature of the furnace itself due to the requirements of glass manufacture which went on as usual in the huge crucibles of the factory, and these changes affected to a certain extent the crystal structures obtained. Fire-clay crucibles of various sizes were used, the melting being done in large crucibles, the crystallization in smaller ones of 150 c. c. capacity. The crucibles when filled were carefully covered and placed on refractory tiles. They were first warmed to dark red heat and then thrust into the position of maximum temperature. After a few hours they were drawn to the second position at the inner mouth of the opening, and finally, after remaining there for several days were drawn within the small chamber where they finally cooled.

Crystallization lasted commonly from one to three weeks, but in exceptional cases the crucibles were left in the furnace as long as two and one half months. A few experiments were made on a very large scale in the great factory crucibles where over a hundred pounds of mineral matter was molten at a time. It was found that certain mixtures corroded the crucible violently, while others remained unaffected by contact with the crucible walls. Magmas with high magnesia and low alumina and alkalies acted violently upon the clay, because magnesia has, at these high temperatures, a very strong affinity for alumina, and in the absence of alumina from the mixture combines readily with that which forms the containing vessel. Mixtures of lime and the alkalies, rich in alumina, do not affect the crucible, even after long exposure to the highest temperatures. About two hundred experiments were made in all, and of these 25 per cent. failed owing to various causes. The others produced coarsely crystalline mineral masses in many cases, so that isolation of the minerals for analysis could be accomplished. The mixtures used were prepared usually from pure chemicals Silica was used in the form of the hydrate $SiO_2.3H_2O$; alumina as hydrargillite ($Al_2O_3.3H_2O$); lime, magnesia, and the alkalies as carbon-

ates, iron oxide as hematite, and instead of ferrous iron was used either siderite ($FeCO_3$) or a fayalite-slag (Fe_2SiO_4).

The pulverized substances were intimately mingled and at first carefully heated to drive off the water. For the larger and coarser experiments common commercial mixtures were used, but in all cases the proportions were calculated as nearly as possible with reference to the known composition of igneous rocks. For a special group of experiments, combinations of minerals in theoretical proportion were prepared, in order to test the theory of solutions; the rock-forming silicates are conceived as capable of supersaturation of a magma, and, in proportion to their relative amounts and the nature of the solvent, crystallize out in the order of saturation; all the mineral products were carefully analyzed and the results were checked in each case by carefully sampled quantitative analysis of the mixture *after fusion*, in order that the effect of the addition of new silica or alumina from the crucible walls, by corrosion, might be allowed for. Finally, a special group of experiments involved the melting up of pieces of natural rocks, granite, andesite, basalt and others, and these experiments the author is still carrying on.

The following list will show the great variety of minerals produced by so-called "dry fusion" from silicate magmas:

1. OXIDES: Corundum, Hematite, Ilmenite, Quartz, Tridymite, and a peculiar prismatic variety of SiO_2.

2. ALUMINATES and FERRATES: Spinel, Chlorospinel, Pleonast, Hercynite, Magnoferrite, Magnetite.

3. SILICATES: Sillimanite, Cordierite, Olivine, Forsterite, Fayalite, Monticellite, Enstatite, Hypersthene, Augite, Alkaline Augite, Pleochroic green Augite, Diopside, Wollastonite, Biotite, Lepidomelane, Sanidine, Labradorite, Anorthite, Melilite, Nepheline, Haüyne, Nosean, Sodalite, and Lagoriolite.

The following volcanic rocks were artificially produced: Rhyolite, with flow structures, spherulitic basalt-obsidian; enstatite-basalt with both intersertal-glassy and micro-porphyritic structures; normal basalt with micro-porphyritic structure; augitite with hyalopilitic groundmass; melilite-basalt in both micro-porphyritic and granular forms; and haüyne rocks of intersertal-glassy and granular structures. From mixtures supersaturated with alumina were produced mineral aggregates bearing abundantly crystalline Al_2O_3 in the form of corundum and related minerals. Among these were a cordierite-andesite of glassy or

micro-porphyritic structure, and ophitic spinel-basalt, a spinel-bearing feldspathic basalt of micro-porphyritic and divergent-radial structure, a corundum-bearing nepheline-basalt, melilite-basalt bearing spinel, corundum-nephelinite, and coarsely trachytic corundum-bearing anorthite-nepheline mixtures.

Corundum and spinel have frequently been obtained synthetically by both "wet" and dry methods, and an examination of the literature, no less than the casual production of these minerals in preliminary experiments, showed that an excess of alumina readily induces the crystallization of free Al_2O_3, in the form of corundum, and with relatively high magnesia and iron in addition, produces spinel. The minerals were isolated and analyzed; both green and black varieties of spinel were obtained, the one chlorospinel, the others pleonast and hercynite. A comparison of the magma analyses with the relative amounts of these minerals produced, shows that alumina plays the principal rôle in the production of spinel as well as corundum. On the hypothesis that the crystallization of free alumina indicates supersaturation, it was believed that precise saturation, or the condition of the magma after the excess of Al_2O_3 had crystallized out, should give a ratio of alumina to the bases of 1 : 1, that being a constant in most of the aluminosilicates (feldspar, nepheline, haüyne, sodalite, mica, etc.). This was confirmed by eight analyses of the glass from which the corundum and spinel had crystallized; these gave the ratios

$(K_2O-Na_2O-CaO):Al_2O_3:SiO_2=$(1b) 0.9:1:1.9; (2b) 0.9:1:2.3; (3b) 0.9:1:2.3; (4b) 0.9:1:2.3; (5b) 0.9:1:2.3; (6b) 1.2:1:1.9; (7b) 1.1:1:3.4; (8b) 1:1:3.2.

Thus with variable silica, the ratio of Al_2O_3 to the bases averaged = 1.

To confirm this result a special series of test mixtures were melted up and crystallized. These tests, made variously with magmas of the composition of basic and acid feldspars, with the alkalies and silica in varying proportions, and under varying conditions of cooling, gave the following important results:

1. A silicate magma is saturated with alumina, when the ratio of the bases to alumina is equal to 1.

2. Saturated aluminosilicate magmas of mixed composition and of varying silica contents, are capable at high temperatures of dissolving alumina and forming supersaturated solutions.

3. Pure soda-aluminosilicate magmas dissolve alumina in large

quantities; lime-magmas in small quantity and pure potash-magmas are, under the same conditions, incapable of dissolving alumina in excess.

4. Supersaturated aluminosilicate magmas, whether of mixed silicates or simple, with the general composition $MeO.mAl_2O_3.nSi\ O_2$ ($Me = K_2$, Na_2, Ca, $n = 2 - 13$), throw out all the excess of alumina (over $m = 1$) in the form of corundum crystals, when magnesia and iron are absent, and n is less than 6; in the form of sillimanite (or sillimanite and corundum) when n is greater than 6; in the form of spinel (or spinel and corundum) when the magma is rich in magnesia and iron and n is less than 6; or in the form of cordierite (or cordierite and spinel) when Mg and Fe are present and n is greater than 6. In the last two cases sillimanite and corundum may also sometimes crystallize out.

5. The amount of spinel or sillimanite, from magmas rich in magnesia or silica, depends wholly on the excess of alumina present. The same is also true of corundum.

6. The crystallization of corundum and spinel depends, not on the "basicity" of the magma, but only on the ratio of the bases (K_2O, Na_2O, CaO) to alumina. In the experiments, corundum crystallized out from magmas varying in silica from 0 (sodic-aluminate) to 13 (Rhyolite).

7. Rules 4 and 5 are not wholly true for those magmas which contain basic non-aluminous silicates like augite and olivine in any considerable quantity.

8. Corundum, spinel, sillimanite, and cordierite crystallize from silicate magmas according to the general laws governing crystallization from solutions.

In nature, magmas with alumina in excess occur, but are not very common. There are numerous cases of the primary occurrence of corundum, spinel, sillimanite, and cordierite in both plutonic and volcanic eruptives. The development of these minerals about inclusions and by contact metamorphism in clay slates is well known. These four minerals form a genetic group of close affinity in mode of origin. In the Urals there are numerous orthoclase-corundum rocks classed as pegmatites and syenites. Morozewicz describes fully a new type of great interest to petrographers, and of especial interest in connection with his experiments; the new rock he names Kyschtymite after the Kyschtym district in the Urals: it consists of a medium-grained mix-

ture of idiomorphic corundum of pyramidal habit, with anorthite and biotite, and accessory dark green spinel of earlier generation than the corundum, with also apatite and zircon.

A number of remarkable experiments were made with acid magmas of the general composition of rhyolite or granite. By dry fusion at high temperatures it has frequently been demonstrated that tridymite is a more stable form of crystalline silica than quartz. In the case of the partial fusion of a quartzose block of granite, the quartz became transmuted into an aggregate of shingly tridymite flakes, and the same has been noted in nature in inclusions of granite in a porphyry. The presence of alumina in an acid magma was found to prevent crystallization, where a non-aluminous silicate mixture partially crystallized in the form of tridymite and prismatic silica (the latter of the unusual type described by Fouqué and M. Lévy). Vogt, in his exhaustive studies of furnace slags,[1] has called attention to the influence of alumina in "retarding" the crystallization of a glass or a slag, and this fact is well known to glass workers who add alumina to prevent the development of silicate crystals. With the aid of the theory of solutions, this influence is easily explained; in general, supersaturated solutions give large crystals, a lower degree of saturation gives small crystals, and unsaturated solutions under the same conditions develop no crystals at all. Alkaline silicate magmas are capable of dissolving alumina in large quantities; alumina possesses for the alkalies and more especially the alkaline earths a very strong chemical affinity, forming with them very stable and widespread natural compounds. Accordingly alumina in small amount dissolved in such a magma has only the effect of uniting with a portion of the bases in potential aluminosilicate form, and preventing them from crystallizing out as simple silicates which in the absence of alumina would easily saturate the solution. Morozewicz has demonstrated that a very large amount of alumina is required to saturate a solution to the effect of permitting crystallization of the aluminosilicates, as outlined above. When great excess of alumina is present, however, crystallization may be readily induced. Thus the expression, "retarding crystallization," is applicable only to access of alumina up to the critical point of saturation, beyond this its effect is that of an accelerator. The effect, in fine, of a small amount of alumina in a glass, is to produce aluminosilicate

[1] VOGT, J. H. L.: Beiträge zur Kenntnis der Gesetze der Mineralbildung in Schmelzmassen und in den neovulcanischen Ergussgesteinen, Christiania, 1892.

molecular combinations, without saturation, and solidification takes the form of Van t'Hoff's "solid solution," namely an amorphous glass.

Rhyolite and trachyte magmas, with the Al_2O_3 percentage varying from 6 to 20, were fused in large masses under varying conditions, of cooling and for periods of a fortnight or more, solidifying invariably as structureless glass; the same magmas, it will be remembered, with an excess of alumina, developed the minerals of the corundum group with the greatest ease. The attempts were repeated with fluorides and phosphates added, but again without result. Finally success was obtained by adding 1 per cent. of tungstic acid to a rhyolite mixture of the following composition:

SiO_2	77.9
Al_2O_3	12.0
FeO	1.3
CaO	0.8
MgO	0.13
K_2O	3.3
Na_2O	4.6

A completely homogeneous glass was formed by the first fusion in the hottest part of the furnace, and partial crystallization was obtained by leaving the crucible at the inner mouth of the entrance chamber for fourteen days—a temperature estimated to vary between 800° and 1000° C. A heterogeneous mass showing flow structures resulted, yellow and white streaks alternating with bands of gray glass. In the microscope the white zones proved to be aggregates of myriads of bipyramidal quartz microlites, of hexagonal form, extinguishing parallel to the vertical axis, and optically positive. The yellowish streaks were much more abundant than the white, and proved to be composed of hexagonal plates of biotite of very perfect form and showing the truncated edges of the combination: (001) (111) ($1\bar{1}1$) (011). The absorption scheme, pleochroism, color, extinction and double refraction all agree with the properties of biotite. Many of the crystals show corrosion phenomena. Finally abundant aggregates of transparent prisms were observed, sometimes in spherulitic grouping, with extinction usually parallel and occasional twinning. These were believed to be sanidine. There were some other indeterminate colored grains and spicular crystals. The groundmass was essentially an isotropic glass, but showed a spicular microfelsitic structure. There had thus been reproduced by "dry fusion," with the aid of tungstic acid, an association

of the essential minerals of granite—quartz, mica and acid feldspar. The influence of the tungstic acid the author believes to be as follows: after the temperature in the first melting has passed 1000°, neither tridymite nor quartz can form, because at these high temperatures the silica unites with alkalies to form a silicate, in which the tungstic acid is absorbed; it is believed that on lowering the temperature (the position of crucible which ultimately produced crystallization) the absorbed tungstic acid has the effect of decomposing these alkaline silicates and liberating the silica to form quartz. It is not known what compounds the tungstic acid finally forms. Dr. Morozewicz objects strongly to the use of the term "mineralizer," and considers that much harm has been done to the progress of synthetic mineralogy by attributing all obscure reactions to the "mystical action of a mineralizer." He insists that "agent minéralisateur" has no scientific meaning and should be banished from the vocabulary of the mineralogist. This would seem a little unreasonable, in view of the fact that he himself acknowledges that his only success in obtaining crystallization of the granitic minerals was due to the action of a small amount of tungstic acid, which he explains by what at best is only an incomplete hypothesis. Modern petrographers have not ascribed any "mystical" power to the compounds of tungsten, zirconium, boron, fluorine, etc., but have observed that these elements are minor but invariable accompaniments of the crystallization of coarse acid pegmatites. Morozewicz has only added confirmatory evidence from synthesis of the actual importance of these agents to promote crystallization in an acid magma, and whatever they be called, their influence, whether chemical or physical, cannot be denied. Possibly the word "crystallizer" would be more exact than "mineralizer." It is certainly true, on the other hand, as Morozewicz points out, that this latter word has been much abused, and simple reactions have been allowed to pass unexplained as due to the action of a mineralizer, because a fluoride or a borate chanced to be in the equation.

The accompanying plates are reproduced to show the coarseness of crystallization obtained with basic magmas. The basic magmas are those still capable of dissolving free alumina, or, in other words, unsaturated. An enstatite basalt was produced from a mixture of three parts olivine, three parts labradorite, and one part augite. A large mass of this material was fused, a smaller quantity being separated for fusion with iron oxide (hematite) alone, the principal mass having a little

charcoal added to reduce the hematite present to the ferrous condition.

The smaller portion, after crystallization for twenty days, gave a well crystallized yellowish-brown mass. Pyroxene crystals could be seen with the naked eye. In the vesicles of the slag were remnants of unmelted hematite, as well as newly crystallized hematite flakes and brilliant spicular pyroxene crystals, sometimes 1^{mm} long. These crystals showed distinct prismatic, pinacoidal and pyramidal faces, pleochroism, and parallel extinction. In thin section, as shown in Plate IV, Fig. 2, distinct porphyritic structure was observed, with idiomorphic enstatite and olivine in a groundmass consisting of monoclinic pyroxene, plagioclase, magnetite, and a small quantity of glass. The olivine was in short crystals, completely transparent and colorless, of very strong double refraction and parallel extinction. The greater part of the olivine crystallized in spherical concretions. The plagioclase of the groundmass showed twinning with extinctions varying from 10° to 27°, hence, a labradorite. Its crystallization was earlier than the other components of the groundmass. The augite formed aggregates of prisms partly as small phenocrysts, but principally in the groundmass. The order of crystallization was thus olivine, enstatite, monoclinic pyroxene, labradorite, magnetite and augite, glass. The larger mass (over 100 pounds), gave also an enstatite basalt (Plate IV, Fig. 1) with crystals of both orthorhombic and monoclinic pyroxene, and olivine, in a colorless groundmass. This groundmass appeared to be a completely homogeneous colorless glass. Pieces of this glass, heated three days at the temperature of red glow without melting, acquired a trachytic crystalline habit of rough surface, and lost their original glassy luster. The groundmass by this heating, developed a crystalline mixture of tiny plagioclase and augite microlites, showing that long continued application of heat to a supersaturated solution, even in solid condition, could bring about crystallization. In order to test the temperature necessary to produce crystallization, the following experiments were devised. Six crucibles were filled with fragments of this slag and placed in a row between the hottest part of the interior of the furnace and the middle of the entrance chamber. At the end of a month it appeared that the innermost four crucibles contained only glass, which had strongly corroded the crucible walls; while in the fifth and sixth crucibles (those within the chamber) crystalline products had formed. An investigation of preparations from these crucibles showed that the order of crystallization of the component minerals was the same

throughout and forms a constant function of the chemical composition of the magma. Period of crystallization and temperature have an important influence only on the structure of the resulting rock.

The second plate here reproduced (Pl. VII) shows the products of crystallization from an anorthite-nepheline magma without magnesia, consisting principally of corundum, anorthite, and nepheline. This was fused in large masses, producing a well crystallized gray rock. In the microscope the principal mineral is seen to be plagioclase prisms in long rectangular form with distinct cleavage and multiple twinning. Between the plagioclase laths is a groundmass consisting of nepheline, magnetite and glass. The physical properties of this plagioclase are essentially those of anorthite ($An_6\ Ab_1$) with the following chemical composition:

SiO_2	46.5
Al_2O_3	34.6
CaO	17.3
Na_2O	1.6

Corundum is enclosed in the plagioclase in the form of circular plates. The groundmass contains many small microlites of magnetite, forming sometimes a rectangular network. Nepheline occurs in short, hexagonal prisms and irregular masses, forming the greater part of the groundmass. There are, in addition, pleochroic yellowish corroded crystalline flakes, which are probably lepidomelane. The glass base occurs in variable quantity in different parts of the crucible.

The systematic subdivision of aluminosilicate magmas, in relation to these experiments, deserves especially thorough examination. The greater part of known eruptives on the surface of the earth belongs to the aluminosilicate group of magmas. The principal and most stable components of magmas are silica and alumina, while the bases are variable and easily replace each other to form both minerals and rocks. Both SiO_2 and Al_2O_3 are capable of crystallizing out in free form by supersaturation, and both (according to the experiments of Thugutt[1] and the theoretical conception of Wernadskij[2]) are capable of playing chemically the part of acids. Silica and alumina are thus conceived to have an analogous systematic significance in the classification of eruptive magmas, granite being a magma supersaturated with silica, and

[1] St. Thugutt, Zur Chemie einiger Alumosilicate. N. J. f. M., 1895, B.-Bd. IX,

[2] W. Wernadskij, Ueber die Sillimanitgruppe, sowie die Rolle der Thonerde in Silicaten. Moscow, 1891 (Russian).

corundum-syenite a magma supersaturated with alumina. Aluminosilicate magmas are thus divided into two great analogous groups, each of which is subdivided into three types, as follows:

GROUP A

1. Magmas supersaturated with Al_2O_3.
2. Magmas saturated with Al_2O_3.
3. Magmas not saturated with Al_2O_3.

GROUP B

1. Magmas supersaturated with SiO_2.
2. Magmas saturated with SiO_2.
3. Magmas not saturated with SiO_2.

In both groups type 2 is the same, a syenite or trachyte magma, simultaneously saturated with both alumina and silica. There are thus five principal types in all, as follows:

1. Magma supersaturated with alumina: corundum-syenite, bearing alkaline feldspars, and kyschtymite bearing lime-soda feldspars.

2. Magma supersaturated with silica: granites, rhyolites, quartz-diorites, dacites, etc.

3. Magma saturated simultaneously with alumina and silica: mica-syenite, trachyte, mica-diorite, and mica-andesite. In this magma the aluminosilicates are the essential minerals. The pure metasilicates and orthosilicates are accessory or absent.

4. Magma not saturated with alumina: gabbro, basalt, diabase pyroxenite and other basic rocks. Obviously this magma is also not saturated with SiO_2.

5. Magma not fully saturated with SiO_2: elaeolite-syenite, phonolite, leucitite, etc.

The magma types 4 and 5 are not identical. A biotite-elaeolite-syenite can be saturated with Al_2O_3 and not fully saturated with SiO_2. In the same way some nepheline rocks may be considered as saturated with Al_2O_3, but do not contain sufficient silica to develop free quartz. In the above scheme it is of course obvious that the rocks belonging to the first type of Group A are least widespread according to our present knowledge of the geology of the earth, and will be discovered, in the opinion of the author, in greater quantity in the future.

It will be seen that in these experiments all the essential minerals of the "neovolcanic lavas" have been reproduced with the exception

of hornblende, and also many rock structures of characteristic habit. These structures are proved to be the result of external conditions of crystallization and also of chemical composition, both in qualitative and quantitative sense. The order of crystallization of the individual minerals depends on no one factor, such as "fusibility" or "acidity," but is the result of a complex equation in which, perhaps, the most important element is the ratio of the quantities of the several compounds dissolved in and composing the solution. One and the same compound can begin to crystallize out sooner or later than another according to the amount which is present. The order of crystallization is different in different magmas, and different substances have different capacity for forming saturated solutions in an aluminosilicate magma. In certain cases temperature has an important influence: magnetite, for instance, forms a saturated solution best at temperatures below 1000° C. At higher temperatures it crystallizes out after olivine. Anorthite crystallizes out more easily at a higher temperature (over 1000°). The process is obviously much complicated by the changes in the magma itself as a solvent, by progressive crystallization of the compounds composing it.

The following are a few of the principles defined by observations up to this date; but final laws of silicate saturation can only be attained by many experiments of character similar to these, which, as in the advanced synthetic work of organic chemistry, shall have thrown light on the structural formulae and atomic relationships of the silicates.

1. Corundum, spinel, sillimanite, and cordierite in magmas supersaturated with alumina, are the first products of crystallization. Spinel and sillimanite crystallize before corundum.

2. Magnetite at a temperature below 1000° crystallizes out in proportion to the supersaturation of a solution with ferric iron and to the amount of other iron compounds. It crystallizes sometimes before and sometimes after augite and plagioclase according to their relative amounts.

3. The different orthosilicates of the type Me_2SiO_4 (olivine, etc.) crystallize first from a magma not supersaturated with alumina.

4. Rhombic pyroxene develops earlier than augite, if the molecular ratio of magnesia (and ferrous iron) to lime is about three or more.

5. The crystallization of augite is very variable.

6. In a magma with haüyne (33 per cent.) in excess of anorthite (23 per cent.) the haüyne crystallizes first.

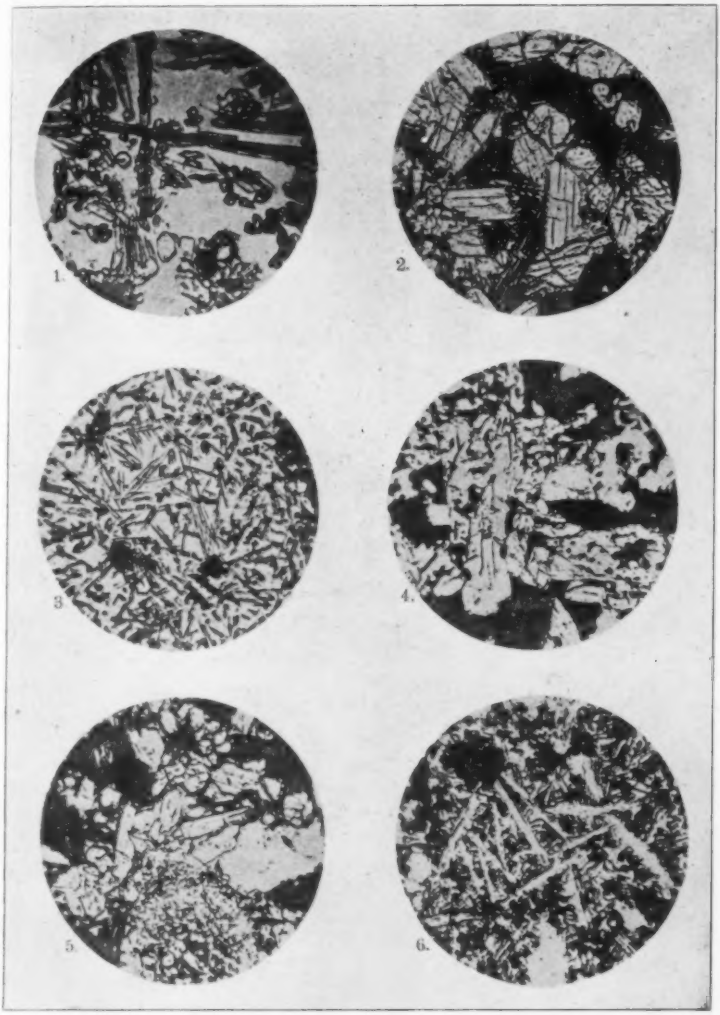
7. In a magma with the ratio of bases to alumina greater than 1, melilite crystallizes after olivine and simultaneously with anorthite.

8. Plagioclase begins to crystallize after olivine, and in many cases after augite, according to the amount present. Nepheline is one of the latest products of crystallization, forming usually a groundmass product between plagioclase laths (mesostasis).

10. The glassy groundmass represents an uncrystallized solid solution and frequently has the composition ($MeO.2SiO_2$) of Lagorio's "normal glass."

With respect to the question of magmatic differentiation, Morozewicz favors rather the hypothesis of one primary magma, chemically differentiated for a single region by means of processes determined in the main by the laws which govern solutions. In many of the experiments described a single crucible showed remarkable variations in structure, coloring, and composition locally. This was especially true of magmas rich in the alkaline earths. In a 100-pound mass, consisting chiefly of alkaline augite, the lower portion showed throughout a higher specific gravity than the upper, with much magnetite below and none above. In common glass-melting, separation of layers of higher specific gravity in the bottom of the crucible has been noticed, these being especially rich in iron, lime, and magnesia. A mass of granite weighing two pounds was melted in large pieces in the hottest part of the furnace, and allowed to glow at the inner entrance of the chamber for five days, producing a glassy mass below with quartz grains unmelted and partially altered to tridymite above. These quartz grains had apparently been floating in the glass; the glassy portion appeared fully homogeneous and was of uniform color; in fact, however, careful separate analyses of the upper and lower portions of the glass showed not only that the upper portion was richer in silica, but that the ratio of the bases was different. Thus Fe_2O_3 showed in the lower layers an increase of .8, MgO of .7, CaO of .4, and alumina of .2. The specific gravity of the lower part was about .1 greater than the upper. The silica percentage of the upper part was 73.65, of the lower part only 59.20. Thus the iron and alkaline earths settled to the bottom, and the silica and alkalies remain in excess above. It is significant that these substances (FeO, MgO and CaO) which form the lower stratum of glass, are the ones which crystallize out earliest from silicate magmas.

In conclusion the reviewer would call the attention of geologists



SYNTHETIC EXPERIMENTS BY MOROZEWICZ

SYNTHETHIC EXPERIMENTS BY MOROZEWICZ

and petrographers to the accompanying plates reproduced from this remarkable monograph, and to the importance of careful study of the results of such experimentation in connection with research in the field. Dr. Morozewicz has written the results of his elaborate synthetic studies in most compact and readable form, the work being contained in 225 pages systematically arranged, well indexed, with each chapter carefully summarized as well as the whole work. He has shown that the synthetic production of rock-making minerals is possible under conditions attainable in any of our large cities, and his work should be a stimulus to further endeavor of the same sort. Analytical work alone is no more capable of solving many difficult problems connected with the origin of the igneous rocks and of ore deposits than are the methods of microscopical petrography. Morozewicz has shown that the same synthetic treatment is applicable to the chemistry of the silicates that has been used for years in the case of the hydro-carbon compounds.

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CAMBRIDGE, MASS.

PLATE III.

Fig. 1. Enstatite-basalt, first stage: olivine, enstatite, monoclinic pyroxene, glassy groundmass; enlarged × 60.

Fig. 2. Enstatite-basalt, second stage; micro-porphyritic structure: large enstatite crystals in a groundmass which consists of augite, labradorite, olivine, and magnetite; enlarged × 60.

Fig. 3. Normal basalt, first stage; augite and magnetite microlites in glassy groundmass (hyalopilitic); enlarged × 60.

Fig. 4. Normal basalt, second stage: great augite masses with inclusions of olivine and magnetite; brown groundmass; enlarged × 60.

Fig. 5. Enstatite-basalt: olivine concretions seen below; enlarged × 60.

Fig. 6. Basalt without olivine, ophitic structure: long plagioclase prisms with augite in the interspaces; black grains of spinel and magnetite; enlarged × 60.

PLATE IV.

Fig. 1. Anorthite-nepheline magma: large anorthite crystals with cleavage cracks and multiple twinning; in the groundmass occurs nepheline, arborescent magnetite forms, etc.; ordinary light, enlarged × 15.

Fig. 2. The same between crossed nicols in polarized light.

Physical Geography of New Jersey. By ROLLIN D. SALISBURY; with an appendix by CORNELIUS CLARKSON VERMEULE. Being Vol. IV of the Final Report of the State Geologist. 8vo, pp. xvi + 170 + 200. Trenton, 1898.

New Jersey has set a good example for her sister states in the character and quality of the physiographic work set forth in this volume. Other states have made an enviable record in other lines of geologic work, but this is the first complete treatment of the physiography of a state we have had in America; and it is all the more notable for having as its author a specialist in physiography of the highest ability.

The plan of the work is, first, a plain statement of the facts of topography in detail, in the three natural topographic regions of the state, and second, the history of the topography.

The State of New Jersey, as a whole, is a part of the Atlantic slope, and though it is only 166 miles long, by about 40 miles wide, it includes portions of all the natural sub-provinces of this slope, *i. e.*, the coastal plain, the Piedmont plateau, and the Appalachian zone. Professor Salisbury shows that to this series another term should be added for the area under consideration, the series then reading from northwest to southeast; (1) *Appalachian* zone, of folded strata; (2) the *highland* area, of crystalline schists; (3) the *piedmont plain*, of Triassic rocks; (4) the *coastal plain*, of Cretaceous and younger strata, this last division covering a little more than the southern half of the state.

The members of this series all have their boundaries practically parallel with the Atlantic Coast, and as they differ widely in the nature of the materials from which they are built, the structure furnishes the natural basis for the division into zones, the topography being of the greatest importance in the interpretation of the geology. These four successive zones have a general slope to the southeast, directly across the structural boundaries, the inner or Appalachian zone having an average altitude of over 1500 feet, while the outer or coastal plain nowhere rises above 400 feet, by far the larger part of it being below 100 feet.

The Appalachian zone consists of early clastics, much folded, the axis of folding being northeast and southwest. Erosion has hollowed out broad valleys in the softer materials, and has left the harder beds standing up as long ridge-like mountains.

The second or Highlands area, made up of crystalline schists, does

not show the topographic regularity which the structure has imposed upon the inner zone, yet it has a deal of relief, being made of block-like mountain masses, flat-topped, of nearly equal elevation, nowhere rising into peaks, and separated by rather broad valleys, so giving an arrangement of two or three ranges of hills with the general northeast-southwest trend.

The third area, the Piedmont plain, has an undulating surface, sloping to southeast, yet interrupted by conspicuous ridges, one of which fronts the Hudson as the Palisades. These ridges are outcrops of trap, and represent dikes or flows of igneous rock.

The coastal plain is coincident with the Cretaceous and later deposits. In the description of all these zones, plates are given, showing various cross-sections drawn to scale, very helpful in getting a clear conception of the actual topographic conditions.

With such a complex structure, erosion has ever been busy, and by the differential erosion, and deposition, a basis is given by which the ever-varying attitude of the land is put on record. This very complex history Professor Salisbury and his assistants have deciphered for the long lapse of geologic time since the Triassic, so a tolerably connected history is given us from the beginning of Cretaceous time, and the ups and downs on record in this area give a very vivid conception of the instability of the earth's crust or the ocean level, or both.

There was a post-Triassic uplift when the Schooley peneplain was formed; then a Cretaceous subsidence and considerable deposits formed; then a slight post-Cretaceous uplift; then a Miocene submergence and more deposition; another elevation and the formation of the great Kittatinny and other valleys, and the emergence of the Palisades by differential erosion; another submergence — the Pensauken — when a broad sound extended from New York Bay southwest to the Chesapeake, and the coastal plain was only half above the sea, as a fringe of sandy islands; then a slight uplift and further erosion, during which time the glacial epoch brought its mantle of ice to the middle of the state, slightly masking the detail of the topography by erosion and deposition of drift; during which time also the southern half of the state was submerged; lastly, a postglacial elevation to present altitude.

This long record is made out by the most careful study of the physiography, by the intelligent mapping and correlation of a vast

mass of detail, and the whole interpretation stands as a monumental work in the young science of physiography.

The complexity of structure, the varying altitudes, the differential erosion, and the glacial interference have given many beautiful examples of readjusted drainage, some cases of which, *e. g.*, the Raritan and the Passaic, deserve to become classic.

The chief changes in postglacial time have been in the way of some readjustments of drainage in the drift, the beach action along the coast, and the building of dunes.

The whole of Part II, pp. 65–170 will be found a very valuable help to the teacher of physiography, and, for these pages alone, should be in every teacher's library. No plainer general statement of river action can be found than is here given (pp. 70–79).

The book is generously provided with maps of fine quality, with diagrams and sections, and with exceptionally clear half-tone insets of characteristic landscapes, all of which add very materially to the value of the work.

In the Appendix is collected a large mass of data, tables of geographical positions, of beachmarks, areas of drainage basins, forest areas, and tide tables. An account of the nationality and distribution of the population, and a statement of work accomplished in the magnetic survey closes the volume.

J. P. GOODE.

Bulletin of the American Museum of Natural History. Vol. X. 1898. New York.

Article IV. *A Complete Skeleton of Teleoceras fossiger. Notes upon the Growth and Sexual Characters of this Species.* By HENRY FAIRFIELD OSBORN.

Article VI. *A Complete Skeleton of Coryphodon radians. Notes upon the Locomotion of this Animal.* By HENRY FAIRFIELD OSBORN.

Article VII. *The Extinct Camelidae of North America and Some Associated Forms.* By J. L. WORTMAN, M.D.

Article IX. *Remounted Skeleton of Phenacodus primaevus. Comparison with Euprotogonia.* By HENRY FAIRFIELD OSBORN.

Article XI. *Evolution of the Amblypoda*, Part I. *Taligrada and Pantodonta*. By HENRY FAIRFIELD OSBORN.

Article XII. *Additional Characters of the Great Herbivorous Dinosaur Camarasaurus*. By HENRY FAIRFIELD OSBORN.

Students of vertebrate paleontology will find interesting material in this bulletin. Professor H. F. Osborn contributes five articles and Dr. J. L. Wortman contributes one. Professor Osborn describes *Teleoceras fossiger*, a complete skeleton of which has been mounted in the American Museum, and calls attention to some of its salient characters. A complete skeleton of *Coryphodon radians* is also described and figured. A study of this skeleton has revealed a number of new morphological features which have an important bearing on the restoration and classification of the animal.

The interesting *Phenacodus primævus* of Cope's collection has been removed from its original matrix and mounted. The bones are thus placed in their natural position and rendered available for detailed study.

"The Evolution of the Amblypoda" is a somewhat extended article and is not complete in this bulletin. The author discusses the origin of the Amblypoda and gives a synopsis of their evolution together with descriptions, relations and classification. The results of of Part I are well expressed in the author's own words, "First, the demonstration of a number of phyletic lines of Coryphodons. Second, that certain Coryphodons approach the Dinocerata in some structures as closely as they depart widely from them in others."

The reptile, *Camarasaurus*, is described from new material which shows characters hitherto unknown. The author points out its relations to *Brontosaurus*, with which it compares in size, and writes of its habits and peculiarities.

Dr. Wortman writes in detail of the Camelidae of North America. He reviews the known genera and species and adds the descriptions of several new ones. The descriptions of many of the old forms are amplified from new material. He makes a careful study of the Cameloids and gives their evolution as near as the incomplete knowledge of the forms will follow.

W. T. LEE.

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